AI in the United Arab Emirates' computing, creative design and innovation K-12 curriculum

A case study

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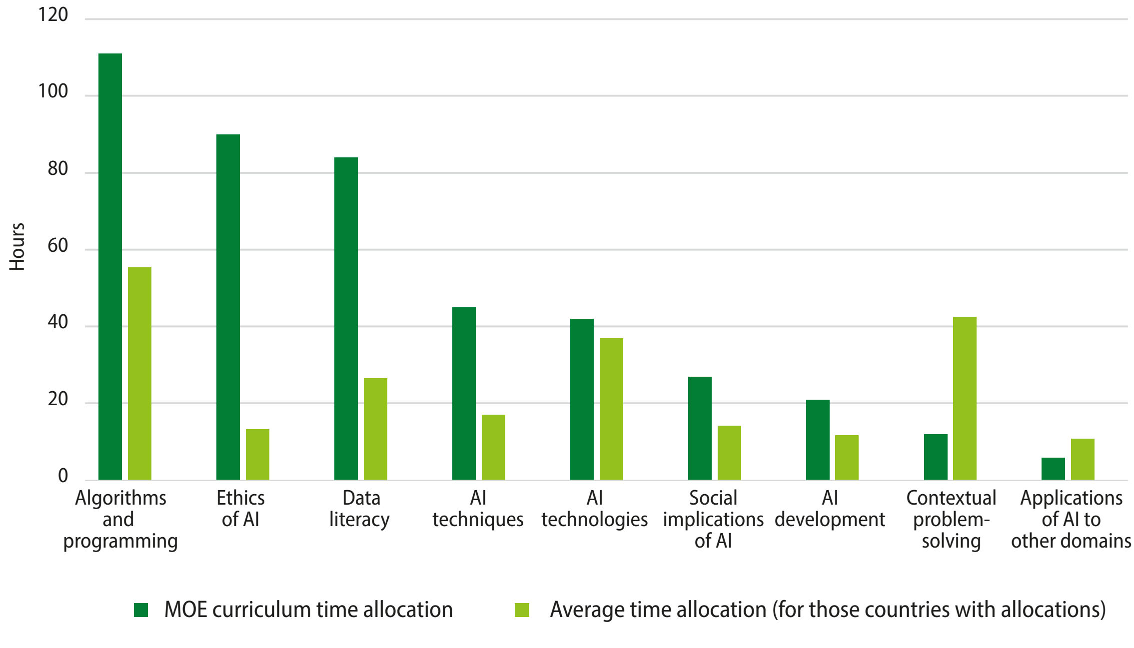
Executive summary

Recognizing artificial intelligence's profound and transformative potential, the United Arab Emirates (UAE) has demonstrated strategic foresight in integrating AI into its national K-12 curriculum since 2017. This pioneering initiative is underpinned by several objectives to enrich students' learning experiences and cultivate their critical thinking and problem-solving capabilities among learners. In an increasingly dynamic and technology-driven global economy, the UAE's curriculum design seeks to equip learners with the essential skills to thrive in the future job market. As a nation, the UAE demonstrates a forward-thinking ethos, promoting innovation and proactivity in its educational strategy. This well-orchestrated effort positions AI as a fundamental building block in preparing the younger generation for the challenges and opportunities of the future world of work.

The case study described herein employed a comprehensive methodology involving a review of the computing, creative design and innovation (CCDI) curriculum by experienced experts in AI education and research. The curriculum's content, learning outcomes, pedagogies and teacher-training needs were analysed and compared with international AI curricula for K-12 and higher education, as well as labour market needs. The case study identified strengths, areas for improvement, and emerging trends and technologies in AI education.

The findings reveal that the curriculum aligns considerably with UNESCO's educational objectives, particularly in emphasizing the ethical and social implications, practical skills and foundational knowledge related to AI. While certain areas required further resources to fully meet UNESCO's goals, the curriculum demonstrated an overall commitment to enhancing students' learning experiences through AI. An analysis of the time allocations (**Figure 1.1**) suggests a strong focus on technical skills, data literacy and ethical considerations, reflecting the evolving demands of the AI industry, albeit less emphasis on contextual problem-solving.

Figure 1.1. Time allocations of the CCDI curriculum compared to international averages

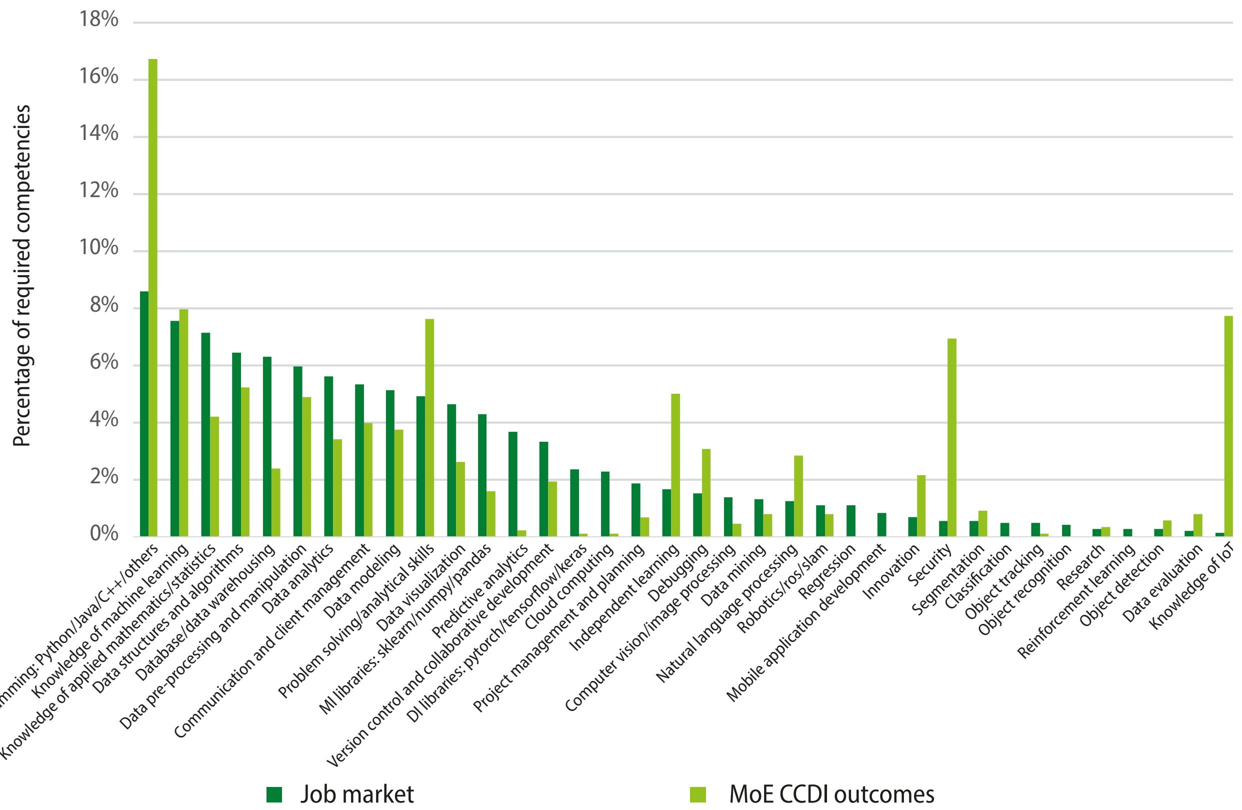


Data Source: Ministry of Education, UAE, 2023

In terms of meeting the needs of the labour market, the CCDI curriculum demonstrates strengths in programming skills, problem-solving, analytical skills and knowledge of the internet of things (IoT), which align well with job market demands, as illustrated in **Figure 1.2**. However, the authors suggest improvements in data analytics, the warehousing of data and databases, and coverage of popular libraries for machine learning and deep learning.

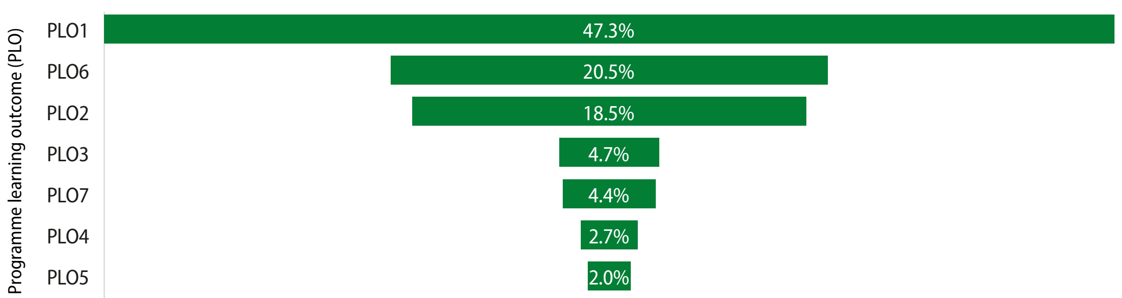
The results also show that the CCDI curriculum effectively prepares students for higher education, as illustrated in **Figure 1.3**, in AI-related areas by providing a strong foundation in engineering, science and mathematics. It aligns well with the essential skills set out in AI curricula at university level, emphasizing problem-solving, critical thinking and practical experience. However, improvements are needed in communication and ethical responsibilities.

Figure 1.2. Comparison between the required competencies in the AI-related job market and the coverage of CCDI outcomes



Data Source: Ministry of Education, UAE, 2023

Figure 1.3. CCDI outcomes mapped to higher education AI curricula learning outcomes

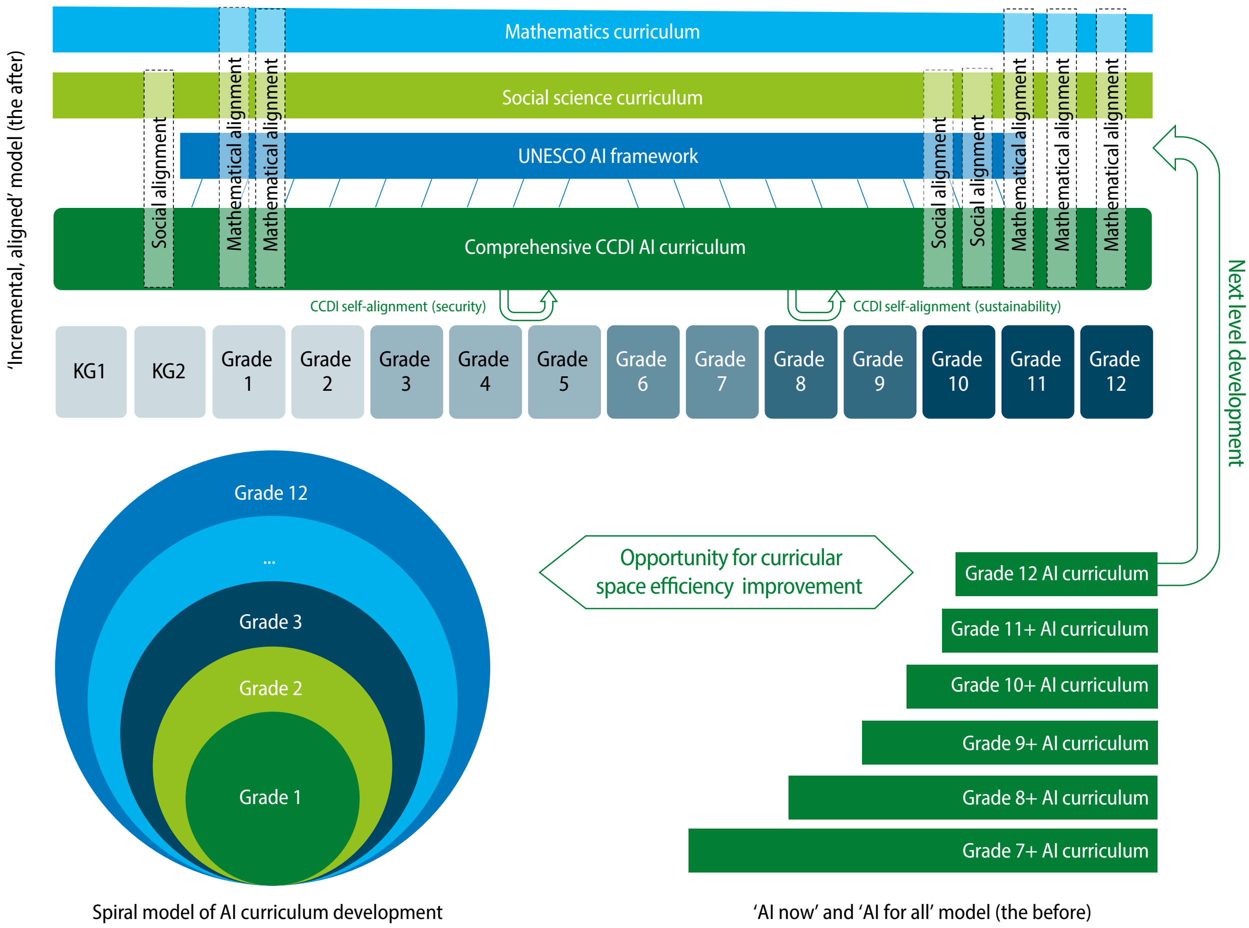


PLO1: Application and problem solving
PLO2: Design with constraints
PLO3: Effective communication
PLO4: Impact and responsibilities
PLO5: Teamwork and leadership
PLO6: Critical thinking and experimentation
PLO7: Life long learning

Data Source: Ministry of Education, UAE, 2023

The report's findings emphasize the vital role of suitable learning tools, supportive environments and comprehensive teacher training for the effective execution of an AI curriculum in K-12 education. The authors propose a multifaceted strategy for teacher upskilling through training, resource provision, mentorship, leadership and evaluation. They recommend expanding the curriculum in areas like data analytics and machine-learning libraries, refining alignment with labour market needs, ethics, AI governance and practical projects, and adopting a spiral development approach (**Figure 1.4**) to introduce skills progressively at all grade levels. Emphasis is placed on integrating AI concepts into familiar subjects, enabling a coherent educational framework that prepares students for a future increasingly shaped by AI.

Figure 1.4. Curriculum plan demonstrating the spiral development for the 'AI now' and 'AI for all' concepts and the next-level development plan



Data Source: Ministry of Education, UAE, 2023

Overall, the case study of the CCDI curriculum highlighted its strengths and areas for improvement and the importance of teacher training and ongoing professional development. Enhancements were suggested to align the curriculum with labour market needs and global standards in AI education while promoting responsible and ethical development and equipping learners for future AI-related careers.

1. Introduction

The United Arab Emirates (UAE) has recognized the potential of artificial intelligence (AI) to transform how students learn and acquire skills since 2017. The country has proactively incorporated AI into its K-12 curriculum content and design to prepare students for the future job market. The UAE aims to enhance students' learning experiences by investing in AI-powered tools, including adaptive learning platforms and intelligent tutoring systems. Governments must start as early as possible to aid in producing a workforce that is equipped with the knowledge and skills to design, develop and deploy AI-powered solutions. Introducing AI curricula in K-12 schools helps students to build a deeper understanding of AI concepts and prepare for careers in computer science, engineering and data analytics, or for driving innovations through AI in their major, even if it is not directly AI-related. Additionally, AI education can help students become critical thinkers and problem solvers, enabling them to use AI to tackle challenges in various domains.

The UNESCO report entitled *K-12 AI curricula: a mapping of government-endorsed AI curricula* (UNESCO, 2022) analyses the current state of AI curricula in primary and secondary schools across the globe, including the UAE. The report's findings are therefore relevant to this case study on the computing, creative design and innovation (CCDI) curriculum designed by the UAE's Ministry of Education (MoE).

The report can serve as a valuable reference for the creation and rollout of the CCDI curriculum, highlighting the key considerations for enabling policies, curriculum design and implementation strategies for AI competency development.

The mapping exercise conducted in the 2022 UNESCO report focuses on structured programmes that have received endorsement from national or regional governments and target learners in general school education from kindergarten to grade 12. As AI technology is relatively new in the K-12 context, a lack of historical knowledge makes defining AI competencies and designing curricula a challenge for governments, schools and teachers. Therefore, the insights provided by the UNESCO mapping report are valuable as they shed light on the current practices of developing and implementing AI curricula in primary and secondary education, including those in the UAE.

Examining and reviewing the UAE's AI curricula is crucial for its MoE and UNESCO. One important motivation for this is ascertaining how the CCDI curriculum compares to other curricula internationally. This will enable policy-makers to determine whether it is on a par with the best practices and standards worldwide or if improvements are necessary to keep up with the rapidly evolving technological landscape. Another motivation for the review conducted in this case study is to provide insights into the strengths and effectiveness of the current curriculum and aspects that need more attention to ensure that learners acquire the necessary skills and knowledge to excel in the digital age. It also aims to assist policy-makers in establishing future directions for developing AI education in the UAE, including integrating emerging trends and technologies not currently covered in the curriculum. Additionally, the review highlights gaps or areas where additional support is required in order to guarantee that teachers and learners have the necessary resources and infrastructure to achieve their goals.

The current case study was commissioned by UNESCO, in partnership with the UAE's MoE and the Regional Center for Educational Planning, following the 2022 publication of the UNESCO mapping report. As an in-depth analysis of an AI curriculum, this review focuses on all aspects of the UAE's CCDI curriculum, including its vision, goals, design trajectory, benchmarks, content, domains, strands, learning outcomes, development and validation mechanisms, alignment, preparation of learning tools and required environments, suggested pedagogies, and teacher-training needs. It complements the 2022 mapping report by providing specific insights into the implementation and effectiveness of the CCDI curriculum in the UAE.

The case study aims to guide the future planning of enabling policies, the design of national curricula or institutional study programmes, and the implementation strategies for AI competency development. It aims to evaluate the curriculum's relevance to labour market needs and international standards, and provide insights and recommendations for developing and implementing the AI curricula elsewhere.

Finally, the case study explores the integration of emerging trends and technologies that are not currently covered in the CCDI curriculum.

1.1 Literature review

This case study expands the analysis beyond the UNESCO *K-12 AI curricula* mapping report (UNESCO, 2022) by incorporating other relevant research and studies to offer a more comprehensive review. This section briefly explores the literature on programmes that integrate AI education at K-12 level, including their design, delivery and effectiveness, as well as issues they raise around ethics and teacher training.

Integrating AI education in K-12 classrooms

Integrating AI into education is becoming increasingly important as technology plays a more and more central role in our daily lives (Dai et al., 2022). As AI and machine-learning tools become more prevalent, students must have a foundational understanding of these technologies (Aruleba, 2022). This is particularly relevant in K-12 classrooms, where the incorporation of AI education has garnered significant interest (Dai et al., 2022).

According to Hutchins et al. (2018), the successful integration of learning environments for computational thinking, science, technology, engineering and mathematics requires a thoughtful approach that considers both learner-centred and classroom-centred design. Various factors must be considered, including the learning goals and capabilities of students, the technological capacity of the classroom environment, and the combined impact of teachers and technology on classroom dynamics, the curriculum and learners' progress. Open-ended learning environments have shown promising results, as seen in a semester-long implementation study in a high school physics classroom.

Furthermore, the implementation of AI in higher education (HE) has been examined from the perspective of Romanian academics by Pisica et al. The research indicates that implementing AI in HE can lead to learning gains, improved skills and competencies, better inclusion and increased administrative efficiency (Pisica et al., 2023).

However, integrating AI into K-12 education is arguably a more complex process that requires collaboration and negotiation among various stakeholders. Teachers, policy-makers and external partners must all shape the curriculum to ensure that students have access to AI education. A study among computer science teachers revealed that curriculum decisions were influenced by educational policies, AI faculty at partner universities, and students' media and technology environments (Dai et al., 2022). Additionally, a survey of K-12 students in four African countries highlighted the digital divide, with some already using machine-learning tools while others lag behind (Aruleba, 2022).

These findings emphasize the importance of AI education in schools and the need for collaboration and support from stakeholders to provide equitable access to these critical technologies. As AI continues to advance, integrating it into education becomes an essential step in preparing students for the future.

Effectiveness of AI education programmes for K-12 students

Despite the increasing popularity of AI education initiatives, most prior reviews have been based on non-empirical reports, with only a descriptive summary of such programmes. In 2022, a systematic review of empirical studies in K-12 contexts revealed that AI teaching programmes positively impact students' motivation, engagement and attitude. Still, there is a lack of research objectively measuring students' knowledge acquisition (Jang et al., 2022). Few studies have evaluated the effectiveness of tools and curricula designed to teach K-12 students about AI, and even fewer have addressed students' learning about AI-based conversational agents (Van Brummelen et al., 2021). Therefore, it is essential to develop practical programmes that can improve each learner's creative problem-solving capacity, AI literacy and attitude towards AI, while also considering pedagogical design, assessment and evaluation of the learning outcomes (Jang et al., 2022; Van Brummelen et al., 2021; Yue et al., 2022). Future AI education initiatives should optimize students' engagement, address a range of abilities, and foster collaboration among teachers (Van Brummelen et al., 2021).

Designing effective AI curricula for K-12 education

As the demand for AI-literate workers rises, developing the next generation's AI competencies becomes increasingly critical. While research on AI curricula for early childhood education is scarce, it is evident that there is a lack of conformity. To achieve AI literacy among young students, three competencies are essential: AI knowledge, skills and attitudes. These can be nurtured through problem-based learning approaches and using a social robot as a learning companion (Su and Zhong, 2022).

Moreover, cultural competence, humanistic thinking and ethical considerations should be emphasized in AI education. Integrating elements of cultural competence within technological mediums has proven effective in helping students understand complex concepts in computer science. Also, ethics of AI and cultural competence significantly influence AI content in high school students (Sanusi and Olaleye, 2022), underscoring the crucial role of ethics in AI learning. Therefore, stakeholders and educators should prioritize these elements when designing AI content and instructional materials.

Ethical considerations and teacher training in AI education

AI has the potential to revolutionize education by supporting students' learning and aiding teachers with automated assessments and other applications. However, AI's ethical and societal implications in education are often overlooked, which highlights the importance of introducing AI education to K-12 students and teachers to promote the ethical and responsible use of these technologies (Akgun and Greenhow, 2022). Exposing young people to computer science concepts and sub-fields, such as artificial intelligence, can help bridge the gap between their incomplete perceptions and the high demand for jobs in this field. With AI technologies' rapid advancement and deployment, teacher training is crucial for the success of hands-on workshops aimed at introducing young people to these topics (Lombart et al., 2020). Two recent studies explored different aspects of AI education for instructors. One study in Hong Kong Special Administrative Region (SAR) of the People's Republic of China used a qualitative research approach to identify six categories of teachers' conceptions of AI education, including technology bridging, knowledge delivery and ethics establishment (Yau et al., 2023). The study concluded with two learning paths that can be used by trainers and policy-makers to enhance teachers' competence in teaching AI. The first path, aimed at both technical and non-technical teachers, is AI Knowledge and Pedagogy Enhancement, which is acquiring the foundational knowledge and skills for teaching AI. The second learning path is AI Integrative Learning for Experienced Teachers and Curriculum Designers. This path focuses on integrating AI into different subjects and designing holistic AI education by considering the entire school curriculum. Another study conducted a systematic review of the literature relating to AI and machine-learning education at the school level (Mahon et al., 2023). It found that most research concentrates on students, and there is a lack of research on teachers, experts, parents and the wider school community. Additionally, the content covered in the courses described in the research varies widely, possibly because there is so little alignment to computer science frameworks or curricula.

Pedagogical approaches for teaching AI in K-12

Research is currently being conducted to address the lack of evidence and understanding surrounding the teaching of machine learning in K-12 settings. The researchers aim to identify and explore pedagogical approaches incorporating the underlying theories and methods of teaching machine learning to K-12 learners (Sanusi, 2021). To tackle the challenge of designing and implementing AI-related curricula for this level, the study conducted by Chiu et al. (2021) proposes a curriculum design model that includes content, process, produce and praxis, and highlights six key components: AI knowledge, AI processes, the impact of AI, its relevance to students, teacher-student communication and flexibility. Studies have also shown that problem-based, project-based and collaborative learning pedagogies used in HE institutions could be adapted to suit K-12 contexts; a survey of the literature revealed that active, inquiry-based, participatory and design-oriented learning could be suitable for teaching machine learning in these settings (Sanusi and Oyelere, 2020). However, despite AI resources becoming increasingly popular among educators and learners, there is a lack of built-in support for assessment and feedback (Druga et al., 2022; Huang, 2019). Therefore, future AI curricula should move towards holistic designs that include support, guidance and flexibility in terms of how AI technology, concepts and pedagogy play out in the classroom (Druga et al., 2022).

Tools and methods for AI education in K-12

AI and machine learning have become essential parts of everyday applications for data analysis in various fields, leading to a growing global trend of teaching AI across K-12 levels (Karalekas et al., 2023; Sanusi et al., 2022). However, educators lack suitable tools and methods for preparing K-12 students for the AI era (Karalekas et al., 2023). A curriculum for 10- to 14-year-old students that integrates computer science and media literacy education can help them to question the concept of intelligence in AI systems. This curriculum uses a role-playing game to introduce the basic concepts of machine learning (Henry et al., 2021). Game-based learning activities in AI courses could promote computational thinking practices. To create an inclusive future where a diverse citizenry can participate in developing AI, robust K-12 curricula should emphasize constructionist learning, designing with ethics in mind, and fostering a creative mindset (Ma et al., 2022). Besides this, unique contextual and cultural values should be considered while producing AI curricula and related resources. Course content promoting teamwork and human-tool collaboration has been shown to contribute significantly to AI literacy regardless of pupils' gender or school type (Sanusi et al., 2022). Moreover, interdisciplinary approaches are recommended as best practice despite the challenges that they pose (e.g. in relation to teacher training) the complexity of IT concepts, and the need for critical questioning. Consequently, Henry et al. (2021) describe a theoretical model for fostering ethical awareness, integrating computer science and media literacy education, and providing pathways for K-12 learners to engage in AI-critical educational experiences.

1.2 Scope of the case study

As a follow-up to UNESCO's 2022 publication on mapping K-12 AI curricula, this case study presents information on developing and implementing AI components of the CCDI curriculum used in the UAE, looking in detail at the associated accomplishments and challenges. It is targeted at AI experts and educational practitioners and policy-makers across the globe (Miao and Holmes, 2022). Its main aims are to:

- Conduct a comprehensive review of the content, design and implementation of the K-12 CCDI curriculum at the UAE's MoE.
- Assess the relevance and effectiveness of this curriculum by evaluating its alignment with labour market needs, international standards and best practices.

The authors are highly experienced experts in AI education and research and development. They have written over 370 publications in the field and hold positions at leading and internationally recognized UAE universities. In addition to their expertise in AI, they have significant knowledge in curriculum development and review, particularly for accreditation bodies like ABET (the Accreditation Board for Engineering and Technology) in the United States of America.

In this case study, first they compare the content related to each learning outcome in the UNESCO mapping report versus the CCDI curriculum. The curricula are clustered by grade and AI-related content is classified into direct AI or AI-supporting skills (e.g. programming, problem-solving, data analysis and data visualization); AI type (e.g. machine learning, computer vision, natural language processing or NLP, symbolic AI and robotics); and application area (e.g. health care, finance and industry). Direct AI skills refer to the specific abilities and knowledge that are related to core concepts and techniques of AI and required to develop, implement and utilize AI systems. On the other hand, AI-supporting skills complement and enhance the use of AI technologies, and provide expertise in specific AI types applied in various domains such as health care, finance and industry. They enable professionals to effectively utilize AI tools and technologies within specific application areas, leveraging the capabilities of AI systems to address domain-specific challenges.

The content coverage of the CCDI curriculum is also critically evaluated in the light of the AI curriculum areas defined in the mapping report (UNESCO, 2022) and reproduced here as **Table 1.1**. Then, the suitability of the content, student readiness and time allocations are analysed; gaps in the curriculum are identified; and improvements to content are recommended.

Table 1.1. AI curriculum categories, topics and competencies

Category	Topic area	Competency and curriculum considerations
AI foundations	Algorithms and programming	Together with data literacy, algorithms and programming can be viewed as the basis of technical engagement with AI.
	Data literacy	A majority of AI applications run on 'big data'. Managing the data cycle from collection to cleaning, labelling, analysis and reporting forms one of the foundations for technical engagement with using and/or developing AI. An understanding of data and its functions can also help students understand the causes of some of the ethical and logistical challenges with AI and its role in society.
	Contextual problem-solving	AI is often framed as a potential solution to business-related or social challenges. Engaging at this level requires a framework for problem-solving in context, encompassing things like design thinking and project-based learning.
Ethics and social impact	The ethics of AI	Regardless of technical expertise, students in future societies will engage with AI in their personal and professional lives – many do so from a young age already. It will be important for every citizen to understand the ethical challenges of AI; what is meant by 'ethical AI'; concepts such as transparent, auditable and fair use of AI; and the avenues for redress in case of unethical or illegal use of AI (e.g. that which contains harmful bias or violates privacy rights).
	The social or societal implications of AI	The social impacts of AI range from requiring adjustments to legal frameworks for liability, to inspiring transformations of the workforce. Survey respondents were asked about the extent to which their curricula targeted these issues. Trends such as workforce displacement, changes to legal frameworks, and the creation of new governance mechanisms were given as examples.
	Applications of AI to domains other than ICT	AI has a wide range of applications outside of computer science. The survey asked participants whether and to what extent AI applications in other domains were considered. Art, music, social studies, science and health were given as examples.
Understanding, using and developing AI	Understanding and using AI techniques	This area included (1) the extent to which theoretical understandings of AI processes were developed (e.g. defining or demonstrating patterns, or labelling parts of a machine learning model); and (2) the extent to which students used existing AI algorithms to produce outputs (e.g. training a classifier). Machine learning in general, supervised and unsupervised learning, reinforcement learning, deep learning and neural networks were given as examples of AI techniques.
	Understanding and using AI technologies	AI technologies are often human-facing applications which may be offered 'as a service'. NLP and computer vision were given as examples. Respondents were asked about the extent to which learners used existing AI technologies to complete tasks or projects, and/or studied the processes of creating these technologies.
	Developing AI technologies	Developing AI technologies deals with the creation of new AI applications that may address a social challenge or provide a new type of service. It is a specialized field requiring knowledge of a range of complex techniques and skills in coding, mathematics (especially statistics) and data science.

Source: UNESCO, 2022

The second main concern of the review is to evaluate the mapping between the learning outcomes in the UNESCO mapping report and those of the CCDI curriculum, considering coverage and the strength, suitability and appropriacy of the mapping. These evaluation criteria enable the authors to shed light on the clarity, rigor, depth and alignment of the CCDI learning outcomes. Based on the analysis, they identify outcomes that may need to be improved, realigned or added.

Finally, regarding the implementation and approach to delivery, the review investigates the learning activities by assessing the environment, teaching platform and tools used in students' practical work, as well as the activities' relevance, differentiation and support for innovation and creativity. The authors seek to determine whether the curriculum's delivery approach and method appropriately and effectively integrates the use of technology and digital resources, such as simulations, programming tools and online materials. Summative assessments to evaluate students' learning are also considered, to ensure they align with the curriculum's goals and objectives. The authors conclude by identifying gaps and making recommendations to improve approaches to the delivery of learning.

2. Computing, creative design and innovation (CCDI)

2.1 Vision and Goals

Having gained insight into the approaches taken by previous studies to evaluate AI curricula in various countries, we now narrow our focus to the CCDI curriculum in the UAE. The vision of the CCDI programme is centred around developing an enriched Emirati school graduate who embodies a creative and innovative mindset and is equipped with the skills and abilities to solve real-world problems. The programme envisions nurturing students' innate creativity and encouraging them to think critically and explore innovative approaches to address the challenges of the modern world. The programme aims to empower students with the entrepreneurial outlook, tools and knowledge needed to analyse complex issues and propose effective and practical solutions in design, engineering, visual communication, sustainability and computer science. This vision reflects the MoE's commitment to equipping Emirati students with the mindset and competencies necessary for success in a rapidly changing and increasingly interconnected global landscape (Ministry of Education, UAE, 2023).

The goals of the CCDI curriculum for K-12 education encompass a comprehensive development of students' skills, focusing on communication, creativity, collaboration, independent working, active problem-solving and critical thinking. The curriculum aims to provide students with a strong foundation in science, technology, reading, engineering, arts and mathematics (STREAM) skills and develop their creativity, innovation and social awareness. It endeavours to produce graduates who can compete in a global marketplace and contribute positively to society. By integrating these key areas into the K-12 curriculum, the UAE prepares its students to be leaders in technology, design and innovation. Over the past few decades, computers, creative design and innovation have transformed the world and the workforce in many profound ways. As a result, these areas now lie at the heart of the economy and how we live our lives. This new global economy can potentially shift economic power on a massive level, resulting in a growing digital divide worldwide.

This is addressed in the following eight goals of the CCDI programme, which are to:

1. Develop students' skills in communication, creativity, collaboration, independent working, active problem-solving and critical thinking to enable them to design innovative products.
2. Develop students' proficiency in a text-based programming language.
3. Help students foster a mindset that can promote innovation and creative thinking skills by including inspiring stories about the developments in the field.
4. Strengthen students' ability to communicate effectively, both orally and in written form, by introducing general intellectual skills in liberal arts education in the context of computing.
5. Develop students' awareness of ethical and social impacts related to software and hardware and their ability to engage in lifelong learning in CCDI or any field they may choose to enter.
6. Stimulate deep critical thinking in students by regularly rehearsing fundamental AI principles and concepts.
7. Enable designers and students to understand connections among technologies based on similar principles to facilitate sound designs and cross-fertilization among technologies, discoveries and innovations.
8. Reduce the apparent complexity of the field of AI, contributing to greater understanding, better designs and simpler, more reliable systems.

These goals are intended to encompass a comprehensive development of students' skills.

2.2 Key Ministry of Education Stakeholders

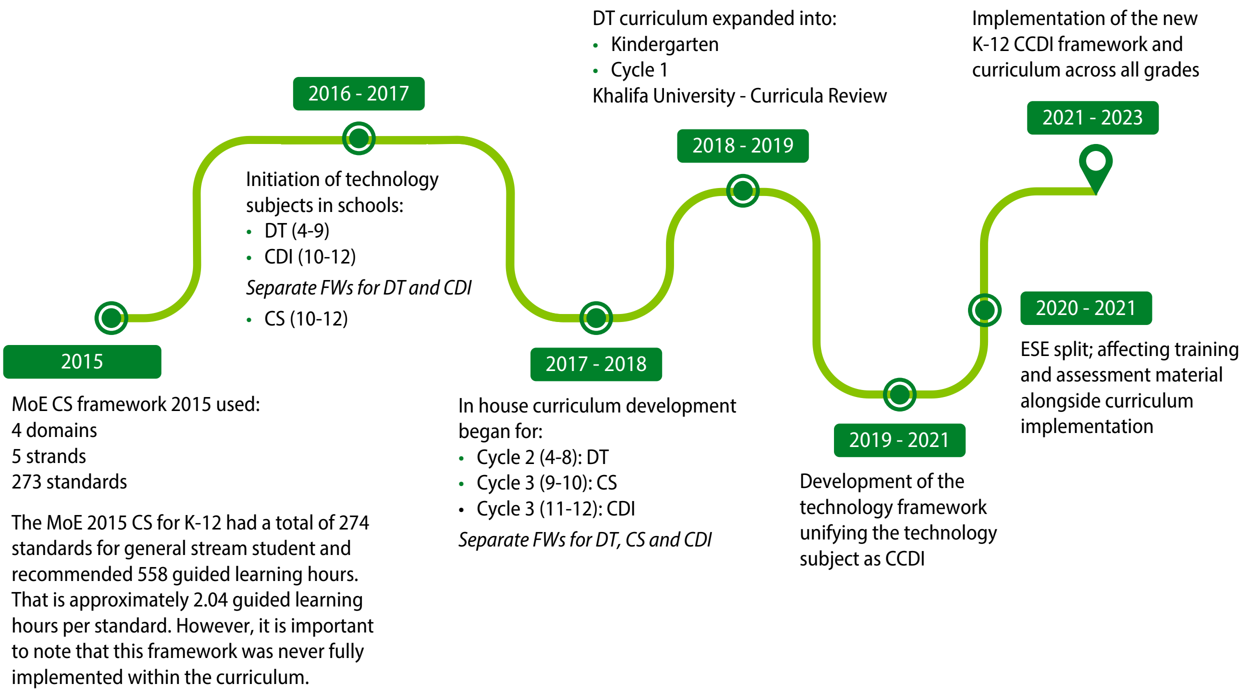
The Ministry of Education engages in extensive collaborations with a wide range of stakeholders, including partners and suppliers, which have been instrumental in developing and continuously enhancing the CCDI curriculum in the UAE. These partnerships enable the MoE to leverage the expertise, resources and support of its stakeholders so that the curriculum remains up-to-date and aligned with industry trends, and students can be equipped with the necessary skills to thrive in the digital age.

2.3 History of the CCDI

The history of the CCDI curriculum traces back to September 2016, when technology-focused subjects like design and technology (DT) and creative design and innovation (CDI) were introduced, signaling a significant shift and the inception of a new era in technology education, despite the prior establishment of computer science (CS) as a subject. These subjects aimed to promote project-based learning, engineering skills, critical thinking, collaboration and problem-solving. Over the years, the curriculum expanded to include lower grades, aligning with the UAE's strategies and the fourth industrial revolution (4IR). Robotics, programming, AI, 3D modelling and electronics were progressively integrated into the curriculum.

In September 2020, the curriculum underwent revision to meet international standards, and a new framework was developed. The implementation of this framework in September 2021 encompassed K-12, focusing on engineering skills, STREAM (Science, Technology, Reading, Engineering, Arts and Mathematics) education, innovation, critical thinking and benchmarking against national and international standards. The aim was to deliver DT, CS and CDI as one subject and provide a comprehensive learning experience from the early grades to high school. **Figure 2.1** shows the timeline of the progress and integration of the CCDI curriculum by the MoE, and then the seven stages of this are each described in turn.

Figure 2.1. Timeline of the progress and integration of the CCDI curriculum by the MoE, 2015-2023



Source: Ministry of Education, UAE, 2023

1. September 2016: Launch of DT and CDI

In September 2016, a pivotal moment occurred in the evolution of technology subjects with the launch of DT in grades 4 to 9 and CDI in grades 10 to 12. The curriculum for these new subjects focused on equipping students with deep content knowledge and essential skills for the twenty-first century workforce. In the lower grades (4-9), they were introduced to the basics of robotics and programming through the Edison Robot. This hands-on experience allowed young students to explore the foundations of technology and develop an understanding of concepts such as coding and automation. In the higher grades (10-12), the focus shifted to electronics and microcontrollers, utilizing the Arduino Discovery Kit, and the curriculum offered both CS and CDI simultaneously, and they ran in parallel. Students were exposed to more advanced concepts, enabling them to engage in complex engineering projects and delve deeper into the world of technology.

Introducing DT and CDI in September 2016 marked a significant step forward in technology education. Schools were provided with the necessary resources to support the implementation of these new subjects, and qualified engineering teachers were recruited to teach the curriculum. This ensured students received high-quality instruction and guidance in exploring design, technology and innovation.

2. September 2017: Broadening the scope

In September 2017, the evolution of technology subjects made another leap forward with the introduction of new skills and topics that linked the curriculum with the UAE government's technology-related initiatives and 4IR strategy. The aims of this were to bridge the gap between high school and university, and prepare students for success in a rapidly changing technological landscape. The revamped curriculum focused on engineering skills, STREAM education, innovation, creative thinking, project-based learning, critical thinking, problem-solving and technology trends.

One of the key highlights of this period was the exposure of students to emerging cutting-edge technologies through the incorporation of AI and inclusion of a new programming language, Python, in the curriculum. Another concerted effort was to enhance students' knowledge and skills in 3D modelling and design, electronics and networking.

This curriculum expansion in September 2017 reflected the importance of staying abreast of technological advancements by incorporating new skills and topics to foster innovation, critical thinking, problem-solving abilities and the other tools necessary to navigate the digital era and contribute meaningfully to the UAE's 4IR strategy.

3. September 2018: Expanding the design and technology curriculum

In September 2018, DT was introduced to students in grades 1 to 3, with a pilot programme implemented in kindergarten. Additionally, CS became available to students in grades 9 and 10, while CDI was offered in grades 11 and 12.

One of the key advancements during this period was the introduction of robotics in lower grades, applying a STREAM approach to teaching and learning. Incorporating robotics brought mathematics and science together, offering students an interdisciplinary learning experience. This approach aimed to strengthen their understanding of fundamental concepts and foster critical thinking skills.

Furthermore, expanding the CS and CDI curricula to lower grades allowed for introducing topics such as 3D modelling, electronics and embedded systems. This deliberate progression ensured that students developed a solid foundation in these areas, paving the way for more advanced learning in high school including AI, 3D design and the building of embedded systems.

The expansion of technology subjects in September 2018 signified a commitment to providing comprehensive and progressive education in engineering skills, STREAM education, innovation, creative thinking, project-based learning, critical thinking, problem-solving and technology trends. By starting early and building upon foundational knowledge, students were prepared for future academic opportunities and demanding careers in technology and design.

4. December 2018 to September 2019: Technology education in kindergarten

Between December 2018 and September 2019, an exciting chapter unfolded in the history of technology subjects as the curriculum expanded to include kindergarten students. Robotics and technology curricula were introduced early to support teaching and learning, and apply the STREAM approach in kindergarten.

Integrating robotics into mathematics and science lessons exposed young children to critical thinking skills and engaged them in hands-on, experiential learning. AI concepts were embedded into lower-grade books to foster an early understanding of this emerging technology, with a focus on the 'Five Big Ideas in AI': (1) perception, engineering and robotics; (2) representation and reasoning; (3) learning; (4) natural interaction; and (5) societal impact (AI4K12, 2023).

This introduction of robotics and AI in the curriculum for kindergarten students gave them early familiarity with critical skills and concepts that would pave the way for their future exploration and understanding of technology.

5. June 2019 to September 2020: Revising the framework

Another key phase in the history of technology subjects took place between June 2019 and September 2020, with a focus on revising the DT, CS and CDI frameworks to meet international curriculum standards.

The objective was to ensure that the quality of education in these three subjects reached the highest level and that the curriculum could be benchmarked against national and international standards. A dedicated effort was made to develop a new framework with a vision for excellence, through meticulous planning of a comprehensive and cutting-edge educational experience and careful consideration of the skills and knowledge that students would need to succeed in an increasingly technology-driven world.

These endeavours in September 2020 laid the groundwork was laid for delivering a world-class education in DT, CS and CDI.

6. 2021: Implementation of new combined framework for DT, CS and CDI

In 2021, the implementation of the new framework had been successfully initiated, transitionally, across K-12, integrating all three subjects into one. This marked a pivotal moment in the evolution of these subjects as the curriculum now facilitated a comprehensive and cohesive experience in technology education.

This new framework was diligently developed by a team of curriculum specialists who ensured that it covered five domains: (1) computer science; (2) engineering principles and systems; (3) design and innovation; (4) sustainability; and (5) visual communication.

During this period, the focus was on implementing the new framework and authoring content based on its guidelines. This involved a comprehensive review of existing curricula and incorporation of new elements to guarantee that the content was up-to-date, engaging and aligned with the evolving needs of the technological landscape.

Implementing the framework brought consistency and uniformity to the technology subjects, encompassing all K-12 grades. This allowed for a seamless progression of skills and knowledge throughout a student's educational journey.

7. September 2022: Unifying the subject name as CCDI

Fast forward to September 2022, the names of the subjects known as DT, CS and CDI were now unified as 'computing, creative design and innovation' (CCDI). Putting all three under one umbrella streamlined and simplified the subject's identity, emphasizing its integrated nature and the interconnected skills and knowledge it involves. With the new framework, consistent implementation and a unified name, CCDI became a cornerstone of education from K to 12, nurturing the development of technology-related skills from an early age.

2.4 International benchmarks

The UAE has comprehensively analysed its new CCDI framework for K-12 education, benchmarking it against the specifications and curricula of nine countries (see **Figure 2.2**). This analysis covered all five of the key domains listed above (i.e. computer science, engineering principles and systems, design and innovation, sustainability and visual communication). The benchmarking process involved evaluating frameworks from the Business and Technology Education Council (BTEC) in the United Kingdom (UK), Ireland, Australia, Singapore and Canada; and the K-12 Framework and Next Generation Science Standards (NGSS) in the United States of America (USA), New Zealand and Finland. By conducting this extensive exercise, the CCDI programme has been able to incorporate international practices into its framework, leveraging the strengths of diverse educational systems. This analysis contributes to developing a robust CCDI framework in the UAE, equipping students with the necessary skills and knowledge to excel.

Figure 2.2. Comparative analysis of the CCDI framework and curricula benchmarking

Computer science domain	Engineering principles and systems domain	Design and innovation domain	Environmental sustainability domain	Visual communication domain
K-12 Framework (USA)	BTEC (UK)	BTEC (UK)	BTEC (UK)	BTEC (UK)
	United Kingdom	United Kingdom	United Kingdom	United Kingdom
	Ireland	Ireland	Ireland	Ireland
	Australia	Australia	Australia	Australia
	Singapore	Singapore	Singapore	Singapore
	Canada	Canada		
		NGSS (USA)		
		New Zealand		
		Finland		

Source: Ministry of Education, UAE, 2023

2.5 Integration support mechanisms

The CCDI curriculum offers resources and assessments to ensure effective teaching and learning, including a coursebook, workbook, interactive activities, assessments and teaching materials/plans. The coursebook serves as the primary source of information, containing the content and concepts that students need to learn in a particular subject. It provides explanations, illustrations and interactive examples and is designed to be user-friendly and accessible to students of all abilities.

In addition to the coursebook, the CCDI curriculum offers a variety of supplementary materials to support student learning. The workbook provides students with additional practice and reinforcement of concepts covered in the coursebook. Interactive activities, such as quizzes, games and simulations, engage students in active learning, allowing them to apply their knowledge in a fun and stimulating way. Assessment strategies are also an important resource, helping teachers to measure student learning and provide feedback for improvement. Teaching materials, such as lesson plans, presentations and worksheets, assist educators in delivering engaging lessons that align with the curriculum standards. These different types of resources and assessments provide a comprehensive and effective approach to teaching and learning in the CCDI curriculum.

The CCDI curriculum utilizes diverse resources to empower students in developing programming, robotics, electronics, design thinking and problem-solving skills, all of which are closely intertwined with the field of AI. Programming skills form the backbone of AI education, enabling students to design and implement AI algorithms and create machine-learning models. Robotics provides a practical platform for applying programming knowledge and exploring the integration of AI technologies in autonomous systems. Electronics knowledge is essential for understanding

the hardware aspects of AI and building circuits and sensors for data acquisition. Design thinking fosters creative problem-solving, so that user-centric AI systems can address real-world challenges. Problem-solving skills are crucial for breaking down complex obstacles and applying computational thinking in developing intelligent solutions. By nurturing these skills, the CCDI curriculum equips students to understand and contribute to the evolving field of AI, so that they may become proficient AI practitioners in various domains.

Some of these resources are shown in **Figure 2.3**:

Figure 2.3. Sample of the resources used in the CCDI curriculum in the UAE

These resources cater to the teaching of AI, providing students with the tools they need to understand and apply artificial intelligence concepts effectively. Among the programming languages utilized, Scratch and Python are particularly popular. Scratch is a visual programming language that allows students to build interactive stories, animations and games using coding blocks. Python, on the other hand, is a versatile language extensively used for web development, data analysis and AI applications. It equips students with a robust tool for coding projects and problem-solving.

In addition to programming languages, the CCDI curriculum uses several hardware resources that allow students to create and program their own electronic devices and interactive objects. For instance, Arduino is an open-source electronics platform that students can use to create and program their own electronic projects. The Raspberry Pi is a credit-card-sized computer that is a versatile platform for learning coding, electronics and robotics, offering a wide range of applications and project possibilities. A Raspberry Pi computer and a camera are the basis for the ORYX autonomous car, which provides students with hands-on experience in programming, computer vision and robotics.

Moreover, the CCDI curriculum uses various software resources that enable students to design and simulate 3D models. Makers Empire provides a user-friendly 3D design and printing platform, allowing students to bring their ideas to life. Through Makers Empire, students can develop their spatial reasoning skills, problem-solving abilities and digital literacy as they create and iterate their designs. Another design tool is Autodesk Fusion 360, a cloud-based 3D modelling and design software with which students can create and prototype their own products, promoting innovation and product development skills. Additionally, the Flashforge 3D printer lets students bring their digital designs to fruition by creating physical objects, fostering prototyping and manufacturing skills.

Furthermore, the CCDI curriculum uses a range of resources that encourage students to develop their networking and cyber-security skills. For instance, the Cisco Packet Tracer is a network simulation tool that students may use to design, configure and troubleshoot computer networks, while the CODE learning platform offers coding courses and resources in various programming languages.

The CCDI curriculum also uses several resources that permit students to learn through gaming and simulations. Minecraft is an immersive sandbox game that can be harnessed as an educational tool to teach coding, problem-solving, collaboration and other topics. KODU is a visual programming language designed for making games and interactive simulations, allowing students to express their creativity while learning coding concepts. Engino Education provides robotics sets that enrich learning by giving students hands-on experience designing, building and programming robots, fostering their engineering and problem-solving abilities.

The CCDI curriculum uses a variety of resources to facilitate students' participation in project-based learning modules as well as coding challenges and competitions. For example, MIT App Inventor is a platform that combines mobile app development with artificial intelligence, enabling students to create their own AI-powered mobile applications. Formula Ethara, on the other hand, is a robotics competition that engages students in designing and building Formula-1-style race cars, promoting teamwork, innovation and problem-solving skills. Lastly, Machine Learning for Kids is an educational platform that introduces students to machine learning concepts through interactive projects and activities.

2.6 Per-cycle sample resources

The CCDI curriculum framework is divided into three cycles, creating a complete course that prepares students for several different paths through further and higher education and careers in the technological world. Each cycle consists of several grades: cycle 1: grades K–4; cycle 2: grades 5–8; and cycle 3: grades 9–12.

Cycle 1: Students have access to various educational resources that support their learning in different areas. These resources include:

- Remote control, card-based and graphical programming with educational robots: Students engage with educational robots that can be controlled remotely. They learn to program these robots using card-based systems, where they arrange and sequence programming cards to create desired behaviours. Additionally, they explore graphical programming interfaces that enable them to program the robots by dragging and dropping code blocks visually.
- Graphical microcontroller programming: Students are introduced to microcontrollers and learn how to program them using graphical programming interfaces. This allows them to grasp the basics of coding and control the behaviour of microcontrollers through visual programming elements.
- Graphical and text-based programming: Students develop programming skills by utilizing both graphical programming environments and text-based programming languages. They learn to create simple programs using visual blocks and gradually transition to text-based coding to understand programming syntax and concepts more deeply.
- Simple designs using child-friendly computer-aided design (CAD) software: Students explore the design world by using child-friendly CAD software. They learn to create basic designs and models, developing their spatial thinking and design skills in a user-friendly environment.
- Simple device configuration with computer lab resources: Students can work with lab resources to configure and operate simple devices. This hands-on experience helps them understand the functionality of various devices and develop practical skills.

Cycle 2: Students continue to expand their knowledge and skills with a new set of educational resources. These resources include:

- Graphical and text-based programming: Students deepen their programming abilities by using graphical programming environments and transitioning to text-based programming languages. They learn to create more complex programs and understand coding concepts in greater detail.
- Microcontroller programming: Building upon their previous experience, students learn to write code to control microcontrollers, enabling them to create more sophisticated projects and explore the realm of embedded systems.
- Graphical or text-based programming for simple embedded systems and robotics projects: Students gain hands-on experience in programming simple embedded systems and robotics projects. They can choose between graphical and text-based programming languages to develop their projects based on their preferences and learning styles.

- Intermediate designs using child-friendly CAD software: Students advance their design skills by working on more complex designs using child-friendly CAD software. They learn to create detailed models and apply engineering principles to their designs.
- Simple designs using industry-standard CAD software: Students are introduced to industry-standard CAD software, which offers more advanced features and tools. They gain exposure to the software used in various industries and develop skills relevant to real-world applications.
- Simple network configuration using industry-standard network simulation software: Students learn the basics of network configuration using industry-standard network simulation software. They gain practical experience in setting up and configuring computer networks, understanding network protocols, and troubleshooting common network issues.

Cycle 3: In Cycle 3, students can access advanced educational resources that build upon their previous knowledge and challenge them further.

These resources include:

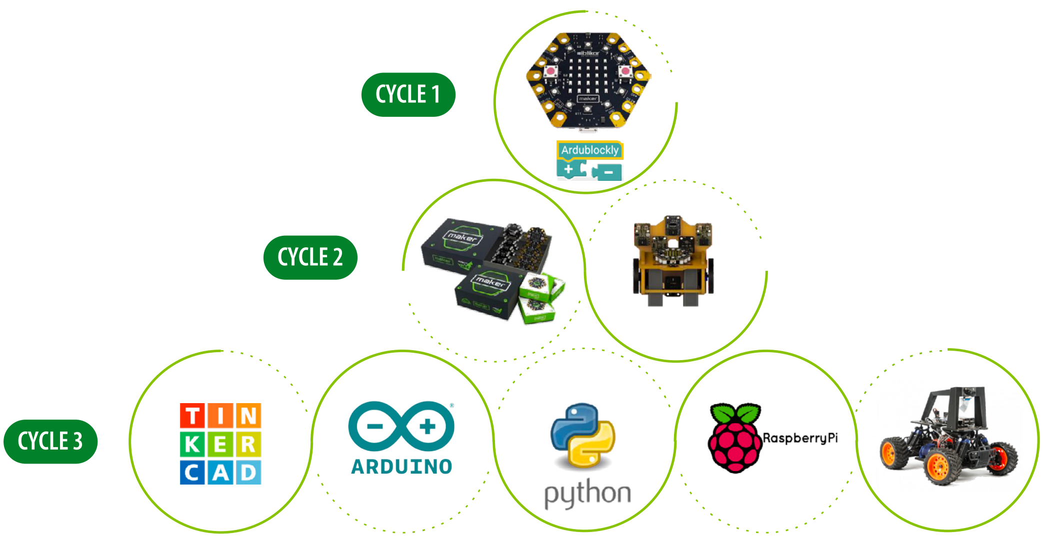
- Microcontroller and mini-computer programming: Students expand their programming skills by learning to program these devices using text-based programming languages, allowing them to undertake complex embedded-systems and robotics projects.
- Text-based programming for complex robotics and embedded-systems projects: Students delve into text-based programming to tackle more intricate projects, gaining problem-solving abilities and a deeper understanding of programming concepts.
- Complex designs using industry-standard CAD software: Students learn advanced design techniques, apply engineering principles, and develop sophisticated models and prototypes.
- Complex network configuration using industry-standard network-simulation software.

The availability of these educational resources throughout the CCDI curriculum enables students to progressively develop their technical skills, problem-solving abilities and creativity. **Figure 2.4** shows a sample of the resources used in each cycle.

2.7 Domains and strands

The CCDI curriculum for K-12 education in the UAE encompasses five domains with core strands that provide students with a comprehensive and well-rounded learning experience. As mentioned earlier in section 2.3, the five domains are computer science, engineering principles and systems, design and innovation, sustainability and visual communication. Students in all three cycles study these core domains, which enables smooth transitions and clear progression through the grade levels.

Figure 2.4. Sample of the resources used in each cycle in the CCDI curriculum



The computer science domain comprises five core strands covering essential concepts in the field. Students develop skills to efficiently use computers and related technology, solving hardware and software problems. They gain knowledge in networking, focusing on components and security. Algorithmic thinking and problem-solving techniques, along with information principles and computation, are emphasized, leading to computer programming skills. They also learn about the characteristics of AI systems, and how to explain and create AI algorithms similar to human reasoning. In grades 11-12, students work on improving AI and machine-learning algorithms to solve computing problems and evaluate the impact of AI systems on a global society.

Engineering principles and systems is an interdisciplinary domain that explores core engineering concepts and the design, integration and management of complex systems. Students think like engineers, progressively building knowledge in electronics, robotics and embedded systems. In grades 5–8, students analyse AI applications in robotics. In grades 9-12, they work on developing solutions to solve a complex problem with given criteria and constraints, using AI and ML models. They also explore practical applications for AI and ML in embedded systems.

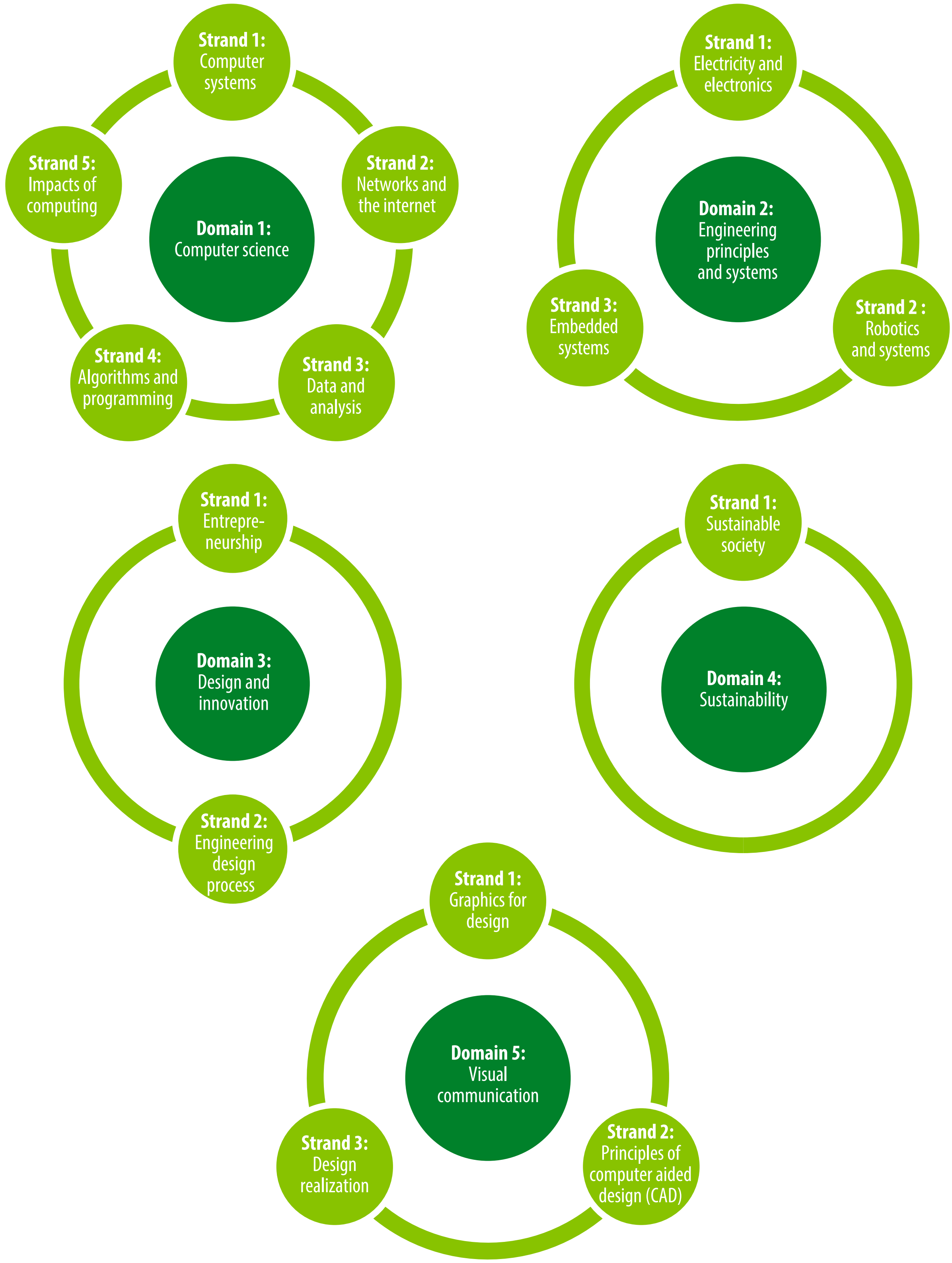
The design and innovation domain integrates STREAM from K-12. Students develop twenty-first century skills like critical thinking, problem-solving, flexibility, adaptability, communication, collaboration and leadership. The flexible domain structure allows for the incorporation of knowledge and skills from other domains.

The sustainability domain enables students to investigate ethics, diversity and environmental responsibility, and make informed decisions for a sustainable future.

The visual communication domain covers three core strands: graphics for design, principles of CAD and design realization. Students progressively develop visual communication skills, creating 2D and 3D shapes, drawings and constructions. They become proficient in various drawing techniques and utilize methods for CAD and manufacturing, such as 3D printing. They also create AI-influenced designs using generative design.

By covering computer science, engineering, design, sustainability and visual communication, the MoE's CCDI curriculum offers a comprehensive and concise educational framework. It prepares students to thrive in the dynamic and interconnected world by nurturing critical thinking, problem-solving abilities and innovation. The core strands in each of the five domains are illustrated in **Figure 2.5**.

Figure 2.5. Overview of the CCDI domains and their core strands



3. Methodology

3.1 Research questions

This research aims to identify the strengths and areas for improvement of the CCDI relative to other countries' curricula and assist policy-makers with valuable insights and recommendations to establish future directions for the curriculum, a benefit that can be leveraged internationally. The following research questions guide the study and help to provide a comprehensive evaluation of the CCDI curriculum in the UAE.

- How effective is the curriculum in preparing students for future challenges in the field of AI?
- What are the strengths and areas for improvement of the curriculum compared to other countries' curricula in equipping students to meet AI-related challenges?

3.2 Research approach and sources of data

To address the research questions, a comprehensive review of the CCDI curriculum is conducted that includes learning outcomes, time allocations and integration mechanisms along with a market analysis to identify the strengths and potential areas for improvement. This research approach involves mapping the AI-related outcomes in the CCDI curriculum to those in the mapping report on AI curricula (UNESCO, 2022).[1]

First, all the CCDI outcomes were listed for all grades from K-12 for the 2021/22 academic year. These outcomes were then mapped to those in the UNESCO report based on their equivalency and similarity. Then, the authors assessed the content where the outcome is introduced and explained, using their experience and thorough understanding of the requirements and standards expected in higher education. Their review included examining the content coverage, learning outcomes and delivery approaches related to AI.

To critically evaluate the content coverage, the study uses the mapping between the CCDI learning outcomes and those in the UNESCO framework (UNESCO, 2022) in order to locate the content related to AI in each grade, classify it as 'direct AI' or 'AI-supporting', and group it according to AI type and application area. The authors then identify gaps and make recommendations on content improvement for the CCDI curriculum.

Specific criteria were designed to assess the learning outcomes and facilitate the mapping. According to the OECD (2019), competence refers to the integration of knowledge, skills, values and attitudes to effectively address complex challenges within a specific context. Therefore, in this case study, the mapping involved categorizing each outcome as knowledge, skills or values.

AI knowledge, skills and values are competencies encompassing a comprehensive understanding of AI concepts, proficiency in utilizing AI techniques and tools, and a responsible and proactive mindset toward AI's ethical implications (Su and Zhong, 2022). Coverage, mapping strength, mapping suitability and mapping appropriacy are included in the criteria to evaluate the clarity, rigor and depth of the CCDI learning outcomes, as well as their alignment to the findings of the UNESCO report. By carrying out an analysis on the basis of these criteria, the authors are able to pinpoint learning outcomes that may need to be added, improved or realigned.

The approach to delivery is then assessed by investigating the learning activities, relevance, differentiation, environment, teaching platform, tools used in practical work, teacher-training programmes, and support for innovation and creativity. The study also seeks to investigate the extent to which the curriculum's delivery method integrates the use of technology and digital resources appropriately.

In addition to the sources touched on in the literature review (section 1.1), the study relies on documents provided by the UAE MoE's Department of Applied Curriculum and Department of Scientific Subjects, including students' activity books, an instructional planner for grades K-12 for the 2021/22 academic year, framework resources, training plans, feedback from companies, subject review documents, lesson plans and curriculum design documents.

1. As noted in chapter 2, the CCDI curriculum covers other subjects apart from AI, but in this analysis only the AI-related outcomes and content are discussed, except where otherwise explicitly noted.

The study team searched the instructional planners for the lessons where the outcomes appeared, and assessed the content in the activity books against a set of criteria (see **Table 3.1**). They used their expertise and professional judgment to score the content while adapting their mindset to the specific topic and its expected treatment, and how it prepares students for future education and the job market.

3.3 Data analysis

To analyse the data and information shared by the CCDI team, the authors adopted the curricular content and learning outcomes defined in UNESCO's report (reproduced in **Table 1.1**) (UNESCO, 2022), which uses three broad categories: AI foundations; ethics and social impact; and understanding, using and developing AI.

The first topic, AI foundations, covers algorithms and programming, data literacy and contextual problem-solving. Programming and algorithms (i.e. sets of instructions that help machines make decisions and perform tasks) are essential for AI because they provide the foundation for building intelligent systems (Casal-Otero et al., 2023). In AI, algorithms analyse data, learn from patterns, and make predictions or recommendations. Developers can create algorithms and develop AI models by writing code in programming languages like Python. These models can be trained on vast amounts of data to recognize patterns and make predictions, enabling machines to perform tasks once thought to be the exclusive domain of humans. AI can only learn, reason and make decisions with algorithms and programming. Therefore, having a solid foundation in these topics is essential to develop intelligent systems that can solve complex problems and positively impact society. Data literacy and security are essential as well because they enable individuals to understand and use data responsibly and ethically while protecting sensitive data from cyber threats. Contextual problem-solving combines project-based learning and design thinking to provide a framework for teaching AI that emphasizes real-world application, collaboration and innovation, and highlights the potential of AI and its limitations. These approaches help students navigate the complex ethical and social considerations associated with AI development and deployment.

The second topic, ethics and social impact, is essential to ensure that AI systems avoid bias and promote diversity and responsible innovation (Talimonchik, 2021). Teaching the social implications of AI is critical if students are to avoid perpetuating inequalities, understand its impact on the labour market, engage with it in a way that benefits society as a whole, and make informed decisions about its development and deployment (Miao and Holmes, 2021). This topic includes applying AI to domains other than ICT, which motivates students with different career aspirations and interests. To engage these learners, it is necessary to expose them to the ways in which AI can drive value and improve our lives in across many areas of application.

The third topic is understanding, using and developing AI. It builds students' capacities to create their own AI models and systems, and keep up with the latest developments in the field. Techniques include supervised, unsupervised and reinforcement learning; and a range of classifiers, detectors and regressors. The technologies that fall under this category, like NLP, large-language models and computer vision, are critical components of many AI systems, have significant real-world applications, and enable students to acquire a more profound understanding of the potential impact of AI on society (Miao and Holmes, 2021). Creating novel technologies and using them to address social challenges, invent a new product, or create or revamp an existing service are all ideal ways to learn and appreciate AI.

The last topic, values and attitudes, focuses on cultivating (1) personal values like interest in computers, persistence and resilience, personal empowerment, reflection, critical thinking and entrepreneurship; (2) social values like collaboration and communication; (3) societal values like respect for others, personal responsibility, integrity and tolerance; and (4) human values, like respect for the environment and commitment to equity (OECD, 2019). These are all pillars of developing responsible and sustainable solutions in the field of AI.

Table 3.1. Criteria used to assess the content in CCDI curriculum materials

Criterion and definition	Performance level 1 (unsatisfactory)	Performance level 2 (satisfactory)	Performance level 3 (exceptional)
Clarity This is an essential criterion in evaluating teaching content because it promotes student engagement and retention (Williams et al., 2021), ensures that the material effectively achieves learning outcomes, promotes inclusiveness and accessibility, and facilitates communication and feedback between teachers and students.	Unclear content leaves more explanations to be desired and uses language and aids that may sometimes be confusing. The flow of the lesson can be improved. The objectives may sometimes be underserved by the content provided, or the instructions may skip an important step.	Clear content provides concise explanations, uses age-appropriate language and includes visual aids such as diagrams or infographics to illustrate concepts. It is well structured, with clear learning objectives, step-by-step instructions and examples that are easy to understand. The material avoids complex technical terms that may confuse students.	Unused for this criterion.
Teaching aids These enhance the learning experience. They include figures (e.g. a depicting neural network architecture), tables (e.g. comparing AI applications), illustrations (e.g. showing real-world AI) and code snippets demonstrating AI development. These aids should be visually appealing, well labelled and relevant to the concepts taught. They are accompanied by clear explanations and instructions on interpreting and using them effectively. They enhance the learning experience by making the material more engaging, accessible and understandable. They can cater to different learning styles, provide hands-on experience, promote comprehensiveness and enable students to develop practical skills.	The teaching aids fall below the expected level. They may need more clarity or relevance and miss opportunities to support students' comprehension of the material. The aids do not cater to different learning styles as well as they could have, resulting in potentially reduced engagement and understanding.	The teaching aids are used to meet the expected level of quality. They are relevant, clear and contribute to the understanding of the material. While they may need to be more innovative and comprehensive, they still enhance the learning experience and support student engagement.	The teaching aids in the content go above and beyond the expected level. They are highly relevant, visually appealing and enhance the learning experience. The aids are thoughtfully designed, provide comprehensive support for understanding AI concepts and cater to different learning styles.
Depth and rigor These are essential in evaluating teaching content because they ensure the material is appropriately challenging, comprehensive, up-to-date and credible. Rigorous and in-depth content enables students to develop higher-order thinking skills, a deeper understanding of the subject matter and practical capabilities that can be applied in real-world situations.	The material avoids shallow treatment but misses opportunities to help students gain the deeper understanding that is a prerequisite to problem-solving and innovation in AI development.	The content delves into the inner workings of AI, providing sufficient details to foster a deep understanding. It incorporates detailed real-world examples and applications to demonstrate its practical relevance and engage students in critical thinking and problem-solving activities.	Unused for this criterion.

Criterion and definition	Performance level 1 (unsatisfactory)	Performance level 2 (satisfactory)	Performance level 3 (exceptional)
Student engagement material The material and activities used for student engagement are critical because they promote active learning, make the material more interesting and relevant, cater to different learning styles, promote inclusiveness, foster practical skills and build confidence. By engaging students in the learning process, teachers can help them develop a deeper understanding of the material and prepare them for success in their future careers.	The materials used for activities may need more interactive elements to facilitate collaborative opportunities and hands-on exploration. Students' engagement is limited, and the activities do not effectively promote active learning or profound understanding.	The materials used for activities encourage active participation, critical thinking and reflection, contributing to satisfactory student engagement.	The materials used for activities offer an exceptional learning experience. Students actively collaborate and apply advanced critical thinking skills, fostering high engagement and deep understanding.
Content appropriacy When teaching AI, it is vital to ensure the content is appropriate for the level of the students. Content appropriacy affects learners' comprehension, interest, confidence and the extent to which they can prepare to meet challenges.	The content may be too complex or advanced for the student's age. It may mistreat a topic by not balancing theoretical and practical content, and/or by black-boxing crucial details. It also misses opportunities to use the foundations built in earlier courses or contribute to the groundwork for future courses.	The content allows students to understand the topic effectively and sustain interest. It is appropriately complex or advanced and yet manageable for students, allowing them to avoid disengagement. The balance is just right to develop a sense of accomplishment and progress. It promotes critical thinking and problem-solving skills, and builds on a foundation carefully cultivated through earlier coursework.	Unused for this criterion.

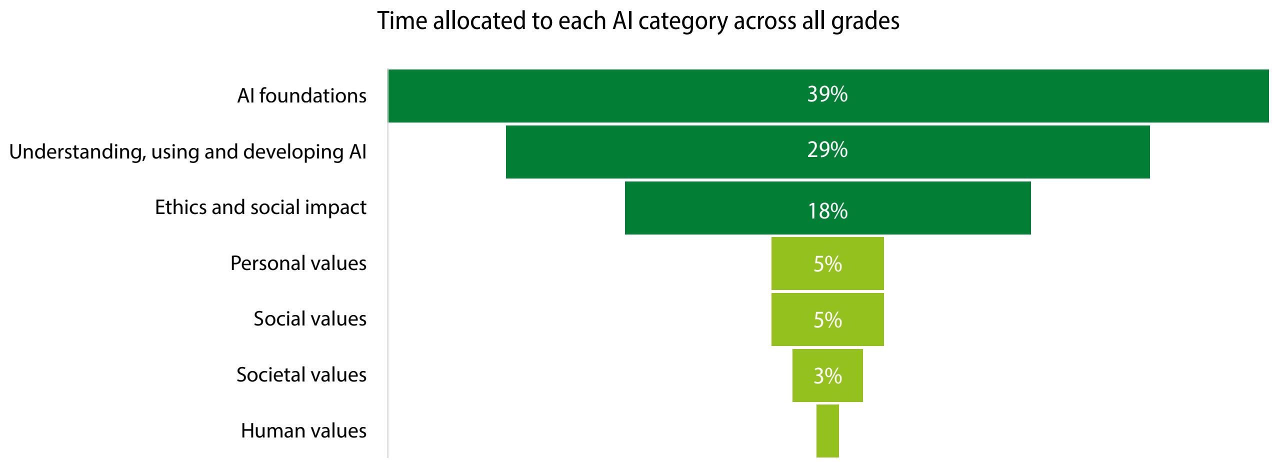
4. Analysis of the CCDI curriculum: Key findings

4.1 Evaluation of content

The CCDI curriculum has seven of the AI topics listed in the *K-12 AI curricula* report (UNESCO, 2022), as shown in **Figure 4.1**, with varying percentages of time dedicated to each. AI foundations accounts for the highest percentage of the time, with 39 per cent of the curriculum devoted to teaching fundamental concepts, principles and techniques related to AI. The topic with the second largest time allocation, 29 per cent, is understanding, using and developing AI, indicating that students are taught practical skills to meet the growing demand for AI-related skills in the job market. Ethics and social impact accounts for 18 per cent of the curriculum time, underlining the importance of equipping students with the knowledge and skills to understand the impact of AI on society and make informed decisions. The personal, social and societal values topics account respectively for 5 per cent, 5 per cent and 3 per cent of the allocation.

Their inclusion ensures students are educated on how AI technologies are developed and used to benefit society without causing harm. Finally, the human values category accounts for only 1 per cent of the curriculum time, possibly due to the belief that teaching human values related to AI may be more effectively integrated into other subjects, such as ethics or social studies.

Figure 4.1. Allocation of time in the CCDI curriculum for each category in the UNESCO report on AI curricula



Data Source: Ministry of Education, UAE, 2023

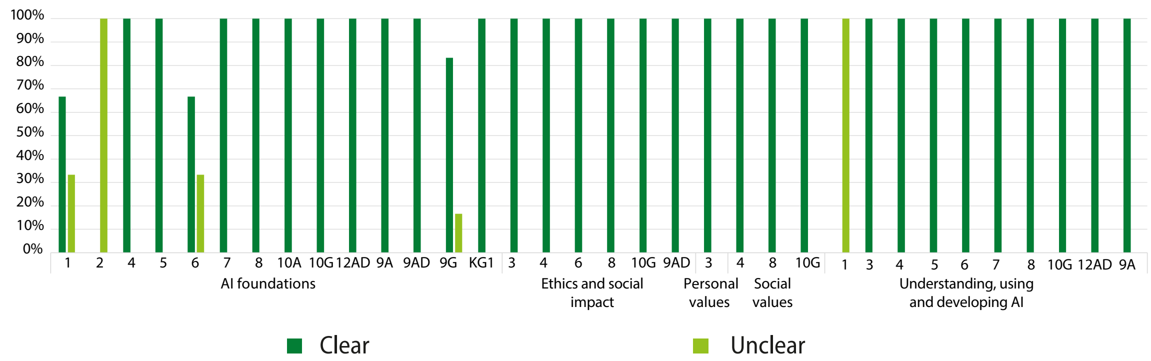
The findings show high scores for clarity and teaching aids, and indicate that most topics fall within the 60-80 per cent satisfaction range for the other three criteria analysed: depth/rigor, content appropriacy and student engagement were scored as 62 per cent, 82 per cent and 77 per cent, respectively. However, there are some areas for improvement identified in **Figures 4.2-4.6**.

The clarity of the CCDI's AI-related content was rated very highly, with 91 per cent being satisfactory and only 9 per cent found to be unclear, as depicted in **Figure 4.2**.

The topics with the highest clarity percentages (all 100 per cent) were ethics and social impact; personal values; and understanding, and using and developing AI. The AI foundations category was the only category with any percentage of unclear content, but still had a relatively high clarity rating of 85 per cent.

Within this category, grades 1 and 6 had the highest percentage of unclear content, rated at only 33 per cent satisfactory, while other grades had 100 per cent clarity.

Figure 4.2. Clarity of the CCDI's content, per grade



Data Source: Ministry of Education, UAE, 2023

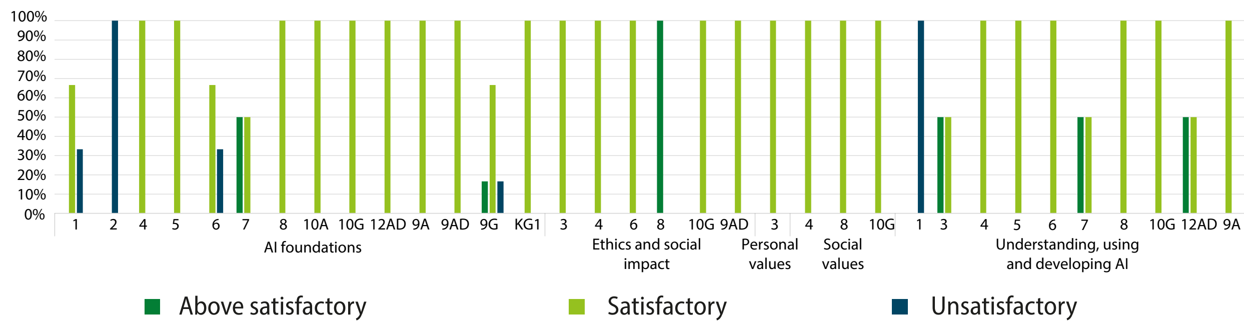
The data indicate that teaching aids are also being used effectively, with 83 per cent of classes receiving an 'above satisfactory' or 'satisfactory' rating (see **Figure 4.3**). Examining the categories individually, ethics and social impact has the highest percentage of satisfactory teaching aids (91 per cent).

AI foundations and understanding, using and developing AI also have a high percentage of acceptable teaching aids, with 78 per cent and 73 per cent respectively. Looking at the percentages by grade level, the teaching aids used in grades 4, 5, 8, 9 and 10 are 100 per cent satisfactory, while grade 2 needs improvement in this area.

As for the depth/rigor of the CCDI curriculum, the data show that 85 per cent of classes received an 'above satisfactory' or 'satisfactory' rating (see **Figure 4.4**), and especially deep learning opportunities were found in grades 8, 9A and 12AD (all 100 per cent). On the other hand, several categories and grades were given low scores for this criterion, including AI foundations and grades 2, 5, 6 and 10A.

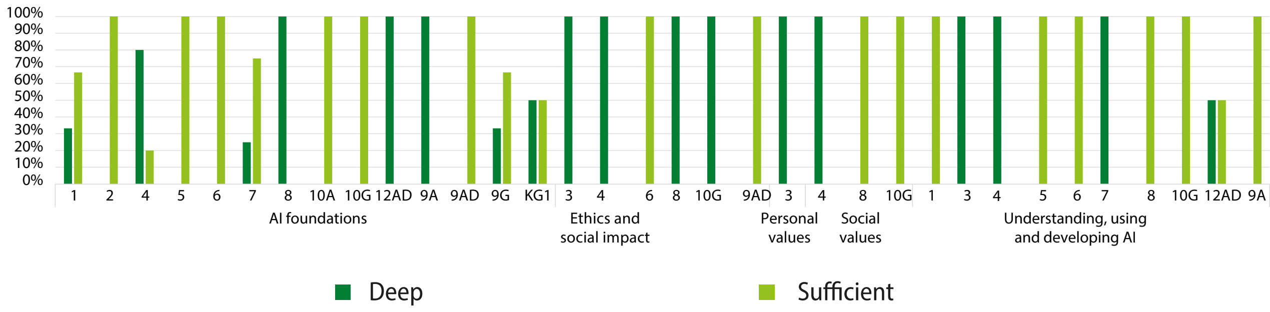
Reviewing the curriculum and instructional practices to incorporate more deep-level learning opportunities in these areas is recommended.

Figure 4.3. Ratings for teaching aids in the CCDI, per grade



Data Source: Ministry of Education, UAE, 2023

Figure 4.4. Depth and rigour of the CCDI's curricular content, per grade

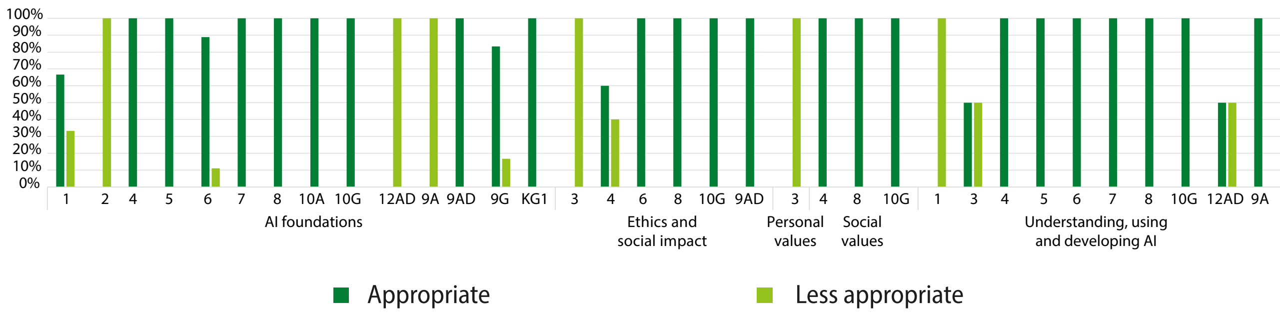


Data Source: Ministry of Education, UAE, 2023

Regarding content appropriacy, the analysis shows that 82 per cent of classes received an 'appropriate' rating, as illustrated in **Figure 4.5**. However, some categories and grades have a high percentage of less appropriate content, such as grades 2 and 12AD (both 100 per cent). Personal values was scored at 0 per cent because it is not well featured in the CCDI curriculum. Therefore, it is recommended to review the content and improve its alignment with the appropriate grade level and its cultural responsiveness.

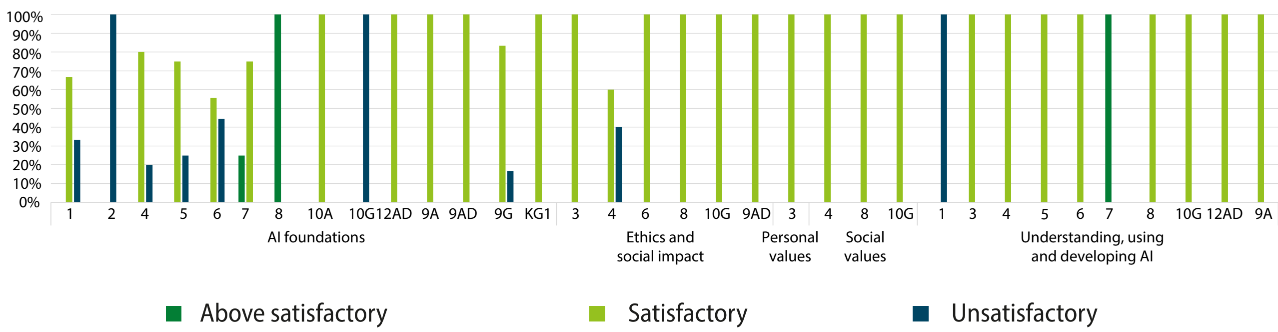
For student engagement (**Figure 4.6**), most categories and grades fall within the acceptable range (77 per cent), with only a few scored at 'above satisfactory', such as AI foundations (5 per cent) as well as grades 7 (25 per cent) and 8 (100 per cent). Hence, more strategies and activities should be incorporated that promote higher levels of student engagement in all categories and grades, especially those with less satisfactory ratings.

Figure 4.5. Content appropriacy of the CCDI, per grade



Data Source: Ministry of Education, UAE, 2023

Figure 4.6. Student engagement ratings for the CCDI's curricular content, per grade



Data Source: Ministry of Education, UAE, 2023

4.2 Evaluation of learning outcomes

The study team used the following four criteria to evaluate the learning outcomes of the CCDI curriculum's AI-related content against the learning outcomes outlined in the *K-12 AI curricula* report (UNESCO, 2022):

- **Mapping appropriacy:** They critically evaluated the appropriacy of the mapping to examine whether that the AI-related content in the CCDI curriculum was relevant to the intended purpose and context. Rating the mapping as 'appropriate' or 'less appropriate' establishes the extent to which the learning outcomes align with the goals of the educational frameworks, are suitable for learners, and support assessment purposes. For example, an outcome on bias may be AI-related, or could be incorrectly mapped.
- **Mapping strength:** Scoring the mapping as strong, medium or weak is important to avoid ambiguity, enhance effectiveness and improve assessment. This is evaluated after it has been ascertained that the outcomes are appropriately mapped (i.e. they are indeed related). It establishes if the alignment (or mapping) is strong or weak (e.g. the same level of expectation, similar action verbs and comparable assessment strategies). A weak mapping may match the topic or theme, but not the level of expectation or types of action verbs or assessment strategies.
- **Relationship to AI:** Some learning outcomes are directly related to AI knowledge and skills, and others are supportive in their relation to AI as they help in the development of mathematical, scientific or computing knowledge and skills that are pre-requisites to AI (e.g. programming).
- **Type of AI technologies:** Some outcomes are contextualized and feature certain AI technologies like robotics and classification as a vehicle for understanding AI techniques like computer vision, neural networks and deep learning. Other technologies and techniques include symbolic AI, NLP, generative AI, reinforcement learning, regression and object detection.
- In doing the assessment, the study team used the mapping already established by the CCDI framework's designers and augmented it with additional AI-related outcomes identified by analysing the curriculum's full set of learning outcomes and mapping them against those outlined in the *K-12 AI curricula* report (UNESCO, 2022). The outcomes assessed and the cycle where they appear are shown in **Tables 4.1-4.3**.

Table 4.1. Knowledge-learning outcomes in the CCDI curriculum and their cycle, mapped to the domains in UNESCO's framework

UNESCO domain	CCDI outcome	C1	C2	C3
	Explain layers of abstraction in computing systems			X
	Use decomposition to identify the parts of problems		X	
	Compare the levels of abstraction and interactions between layers of abstraction in computing systems			X
Algorithms	Identify hardware and software components in a project that collects and exchanges data		X	
	Explain how a project uses hardware and software components to collect data		X	
	Explain how robots know what to do	X		
	Differentiate input and output devices	X		
	Use training and testing data sets to build a model			
	Devise a product, process or program which contributes to a sustainable society	X		
	Select a range of appropriate existing data and procedures in a program to develop a computational artifact			X
	Evaluate the ability of models and simulations to test and support the refinement of hypotheses		X	
Programming	Predict an outcome, highlight a relationship or communicate an idea using data	X		
	Illustrate collected data visually to support a claim	X		
	Select hardware and software components to collect and exchange data in a project		X	
	Demonstrate a project that uses hardware and software components to collect and exchange data		X	
	Explain how a project uses hardware and software components to exchange data		X	
	Analyse a project that uses hardware and software components to collect and exchange data		X	
	Evaluate the hardware and software components used in a project to collect and exchange data		X	
	Design projects that combine hardware and software components to collect and exchange data		X	
	Transform data to make it more useful and reliable	X		
Data literacy	Explain different bit representations of real-world phenomena, such as characters, numbers and images			X
	Evaluate computational tools used to collect data		X	
	Evaluate trade-offs in how data elements are organized and where data is stored			X
	Transform data using multiple encoding schemes		X	
	Evaluate data-collection tools and techniques used to generate data sets that support a claim or communicate information	X		
	Describe some tasks where AI outperforms humans, and tasks where it does not	X		
	Define the basic concept of AI and machine learning		X	
	Describe patterns in data visualizations to make predictions	X		
AI techniques	Compare the three different machine-learning approaches: supervised, unsupervised and reinforcement learning	X		
	Illustrate a multilayer perceptron neural network			
	Describe artificially intelligent robots	X		
AI technologies	Explain how the study of human-computer interaction can improve the design of computing devices			X
	Demonstrate basic concepts and methods in the field of computer vision			
AI applications	Identify AI algorithms similar to human reasoning			
	Identify innovation areas in robotics		X	

Ethics of AI	Describe how AI and machine-learning algorithms can exhibit biases	X		
	Explain examples of bias that have influenced the decision-making of AI		X	
	Describe potential sources of bias in the decision-making of AI			
	Discuss reasons why a website may not be suitable for research due to bias	X		
	Analyse websites that are not suitable for research due to bias	X		
	Identify and evaluate websites that are not suitable for research due to bias	X		
	Evaluate issues of bias and accessibility in the design of existing technologies		X	
	Revise computational artifacts to reduce bias and equity deficits			X
	Demonstrate awareness of copyrights and intellectual property rights while using computational artifacts	X		
	Assess various personal cyber-security issues	X		
	Analyse the methods used to protect personal information from cyber-security threats	X		
	Implement a range of cyber-security measures in a computer system	X		
	Compare various physical and digital information-security measures			
	Explain how physical and digital security measures protect electronic information			
	Identify physical and digital security measures that protect electronic information			
	Discuss how digital security measures protect electronic information			
	Demonstrate how digital security measures are used to protect electronic information			
	Analyse the dangers of displaying personal information online			
	Explain the different ways that people can try to steal personal information			
	Describe different ways you may be vulnerable online		X	
	Explain different ways that you can protect yourself from cyber-security threats		X	
	Determine appropriate ways to store and manipulate different sets of data	X		
	Explain a range of security measures and how they impact the usability and protection of a computing system			X
	Compare the trade-offs between the usability and protection of a computing system for a range of security measures			X
Social impact	Explain the impact of AI systems on a global society	X		
	Analyse the pros and cons of using social media for research			
	Evaluate and discuss the pros and cons of using social media for research and entertainment			
	Discuss ways to improve the accessibility and usability of technology based on the diverse needs of users	X		

Data Source: UNESCO, 2022; Ministry of Education, UAE, 2023

Table 4.2. Skill-learning outcomes in the CCDI curriculum and their cycle, mapped to the domains in UNESCO's framework

UNESCO domain	CCDI outcome	C1	C2	C3
Algorithms	Identify simple sequences in daily processes	X		
	Use algorithms to complete specific tasks	X		
	Describe simple daily processes using sequences of instructions			
	Create an algorithm to complete a specific task	X		
	Explain a range of fundamental data structures and their uses			
	Explain ways in which algorithms can be applied to problems across disciplines			X
	Evaluate data patterns from visual data and create predictions	X		
Programming	Create computer programs to perform various tasks	X		
	Apply existing algorithms to create a computer program			
	Integrate sequences, conditionals and loops into a program	X		
	Examine the technical aspects of the real-world use of robots		X	
	Describe the encryption of information			
	Describe different examples of how encryption can be used		X	
	Apply a method of encrypting information			X
	Explain how the method of encryption used keeps the information safe			
	Demonstrate multiple methods of encryption to securely transmit information			
	Compare different levels of encryption used in secure data transmission			
	Define what a robot is	X		
Contextual problem-solving	Develop programming solutions by breaking down the problem into smaller components that can be solved using constructs such as procedures, modules and objects			X
	Explain the benefits and drawbacks of using specific control structures for program implementation, readability and performance			X
Data literacy	Create interactive data visualizations to help others better understand real-world phenomena			
	Organize data visually to highlight relationships	X		
	Explain a range of privacy concerns related to the collection and generation of data through automated processes			X
	Transform data to make it more useful and reliable	X		
	Describe computational tools used to collect data		X	
	Evaluate a computational model that represents the relationships between different data elements collected from a phenomenon or process			X
AI techniques	Use a classifier to recognize different objects			
	Identify elements by following the nodes within a decision tree		X	
	Test a computer program or algorithm			
	Create an AI algorithm that is similar to human reasoning	X		
	Test the performance of a solution or model		X	
	Identify approaches for determining whether an agent is intelligent			
AI technologies	Modify an existing algorithm/program to enhance/fix a program or process	X		
	Improve AI and machine-learning algorithms to solve advanced computing problems	X		
AI development	Use online collaborative spaces and tools respectfully and responsibly			
	Apply collaboration strategies when creating a computational artifact		X	
	Select appropriate collaboration strategies when creating a range of computational artifacts		X	
	Use tools and methods for collaboration on a project to increase the connectivity of people in different cultures and professions			X
	Appraise tools and methods used for collaboration on a project to increase the connectivity of people in different cultures and professions			X

UNESCO domain	CCDI outcome	C1	C2	C3
Ethics of AI	Analyse the dangers of displaying personal information online			
	Explain the different ways that people can try to steal personal information			
	Analyse the methods used to protect personal information from cyber-security threats	X		
	Explain ways in which software developers protect devices and information from unauthorized access			
	Compare ways in which software developers protect devices and information from unauthorized access			
	Evaluate a range of ways in which software developers protect devices and information from unauthorized access			
	Identify the bias in a training data set		X	
	Conduct research before beginning a design for a solution			
	Describe the pros and cons of using social media for research			
	Compile research before beginning a design for a solution			
	Demonstrate how digital security measures are used to protect electronic information			
	Describe ways that AI systems can be designed to maintain diversity, inclusion and ethics	X		
	Explain the ways in which AI systems can impact personal, ethical, social, economic and cultural practices			X
	Evaluate the impact of AI systems on global society			X
Social implications of AI	Explain how sensitive data can be affected by malware and cyber-attacks			X

Data Source: UNESCO, 2022; Ministry of Education, UAE, 2023

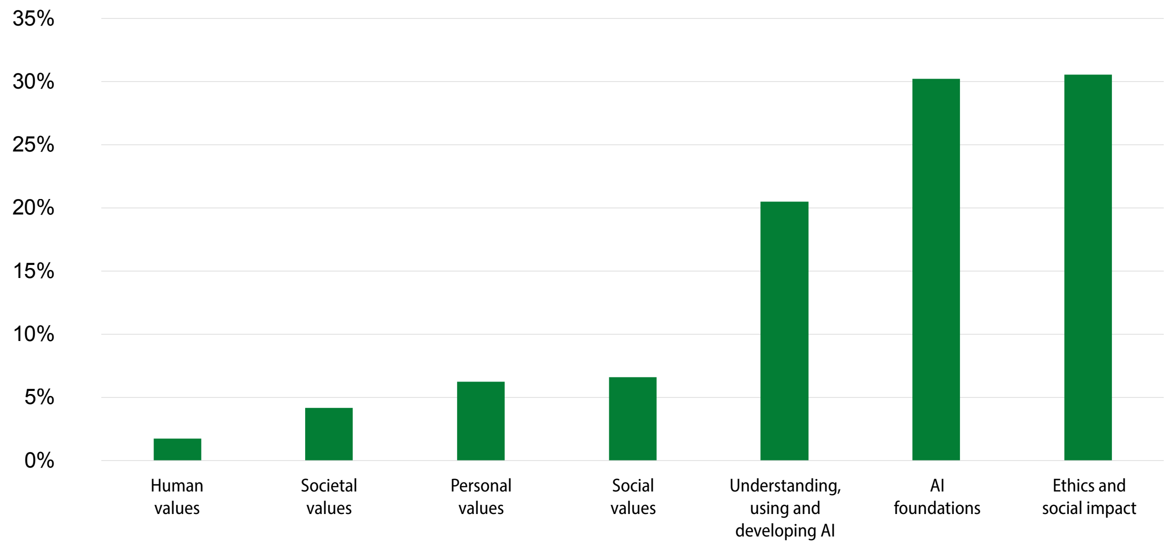
Table 4.3. Values-learning outcomes in the CCDI curriculum and their cycle, mapped to the domains in UNESCO's framework

UNESCO domain	CCDI outcome	C1	C2	C3
Personal value	Identify AI algorithms that are similar to human reasoning			X
	Improve AI and machine-learning algorithms to solve advanced computing problems	X		
	Test computational artifacts to identify bias and equity deficits			X
	Create a prototype of a design using available materials	X		
	Conduct research before beginning a design for a solution			
	Describe the pros and cons of using social media for research			
	Compile research before beginning a design for a solution			
	Explain the impact of AI systems on a global society			
	Discuss ways to improve the accessibility and usability of technology based on the diverse needs of users	X		
Social value	Use online collaborative spaces and tools respectfully and responsibly			
	Apply collaboration strategies when creating a computational artifact		X	
	Select appropriate collaboration strategies when creating a range of computational artifacts		X	
	Use tools and methods for collaboration on a project to increase the connectivity of people in different cultures and professions			X
	Appraise tools and methods used for collaboration on a project to increase connectivity of people in different cultures and professions			X
	Explain the ways that AI systems can impact personal, ethical, social, economic and cultural practices			X
Societal value	Analyse the dangers of displaying personal information online			
	Explain the different ways that people can try to steal personal information			
	Analyse the methods used to protect personal information from cyber-security threats	X		
	Explain ways that software developers protect devices and information from unauthorized access			
	Compare ways that software developers protect devices and information from unauthorized access			
	Evaluate a range of ways in which software developers protect devices and information from unauthorized access			

Data Source: UNESCO, 2022; Ministry of Education, UAE, 2023

The mapping in **Tables 4.1-4.3** is summarized in **Figure 4.7**, which shows that the CCDI developers produced a comprehensive framework covering learning outcomes aligned with various AI categories outlined in the *K-12 AI curricula* report (UNESCO, 2022). The curriculum places significant emphasis on teaching students about AI's ethical and social implications and how to make informed decisions, with 31 per cent of learning outcomes falling under this category. In addition, AI foundations comprises 30 per cent of the learning outcomes, and 20 per cent relate to understanding, using and developing AI, indicating that students are being taught practical skills relevant to today's rapidly changing technological landscape. The percentages related to human, personal, social and societal values are lower. These learning outcomes may be more effectively integrated into curricula for other subjects, such as ethics or social studies, rather than trying to cover them in the AI curriculum.

Figure 4.7. Distribution of the CCDI curriculum's learning outcomes against each UNESCO category



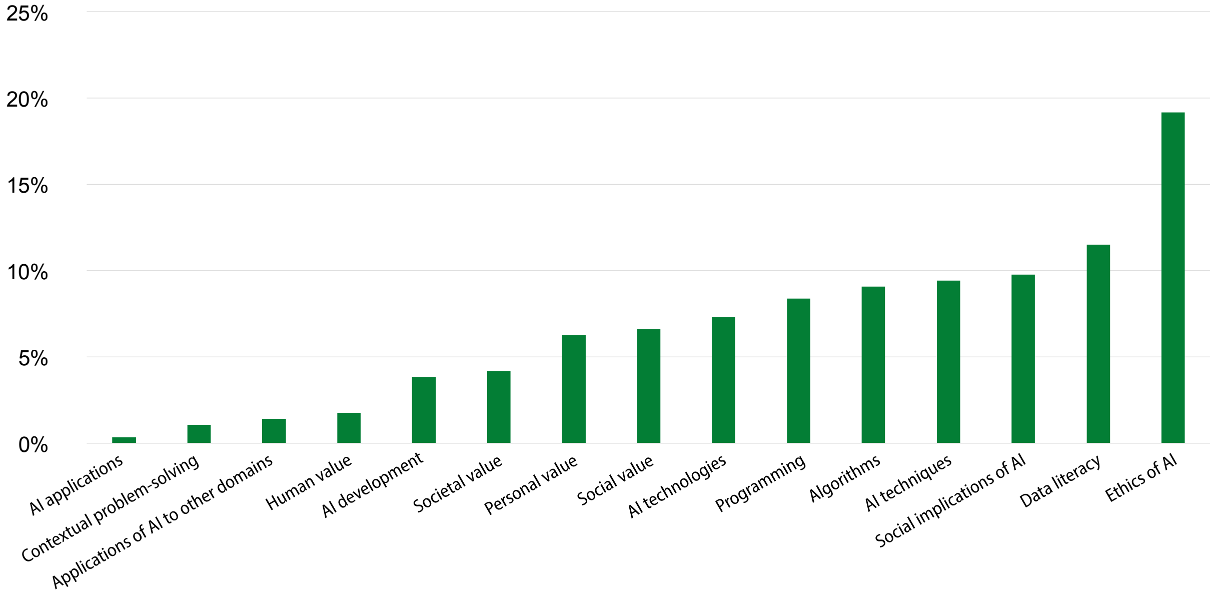
Data Source: UNESCO, 2022; Ministry of Education, UAE, 2023

The CCDI curriculum's outcomes touch on all the 15 of the domains of AI defined by UNESCO, as shown in **Figure 4.8**. The highest percentage of the CCDI outcomes addresses the ethics of AI, at 19.2 per cent, due to far-reaching concerns about AI's impact on society and individuals in the light of its incredibly rapid development. Understanding the impact of AI on individuals and society is also part of the social-value and personal-value domains, which are covered by 6.6 per cent and 6.3 per cent of the outcomes respectively (UNESCO, 2021).

In addition, data literacy and AI techniques account for 11.5 per cent and 9.4 per cent of the CCDI outcomes, reflecting the growing importance of these skills in the digital economy. As for technical design and development skills, the domains of programming and algorithms domains respectively cover 8.4 per cent and 9.1 per cent.

Fewer outcomes focus on the domains of human value, societal value, contextual problem-solving and applications of AI to other domains. This is perhaps because they may not be as relevant to the foundational knowledge and skills that students must acquire at the introductory levels of AI education. The analysis suggests that the CCDI curriculum facilitates the acquisition of knowledge and skills primarily in relation to AI's fundamentals and broader implications, with a lesser focus on the more specialized topics.

Figure 4.8. Percentage of the CCDI curriculum's outcomes covering each of the domains or topics of AI defined by UNESCO



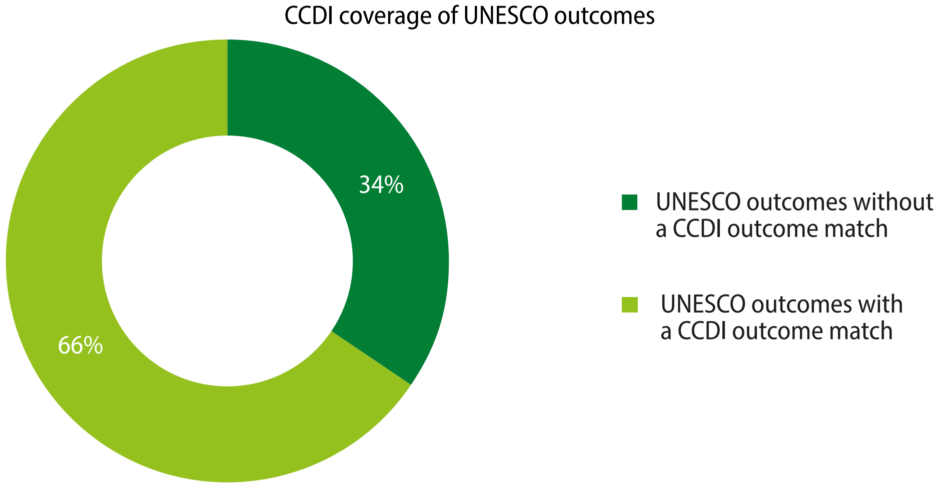
Data Source: Ministry of Education, UAE, 2023

Of the CCDI curriculum's learning outcomes, 66 per cent are aligned with outcomes proposed by UNESCO (UNESCO, 2022), indicating a strong foundation in the fundamental concepts of AI, such as basic programming, machine learning and data analysis (see **Figure 4.9**). However, there are several notable areas where the CCDI outcomes do not match those of UNESCO, and this analysis does not consider any other outcomes or skills that the curriculum may teach beyond those outlined by UNESCO.

While the outcomes cover many key AI skills, the CCDI designers may need to focus more on aligning with global AI education standards, especially with regard to outcomes on creating chatbots; building and running statistical regressions; and using NLP, expert systems, green AI, explainable AI, edge AI and generative AI. These may be areas where additional resources or training could be provided.

Despite the lack of direct alignment, the CCDI curriculum has alternative methods for covering outcomes that do not match UNESCO, like additional resources or courses that address AI's broader ethical and societal implications not covered in the shared documentation related to the CCDI curriculum. Also, the CCDI curriculum prioritizes the development of foundational skills in AI, while leaving more advanced AI topics to be learned in higher education or professional development programmes.

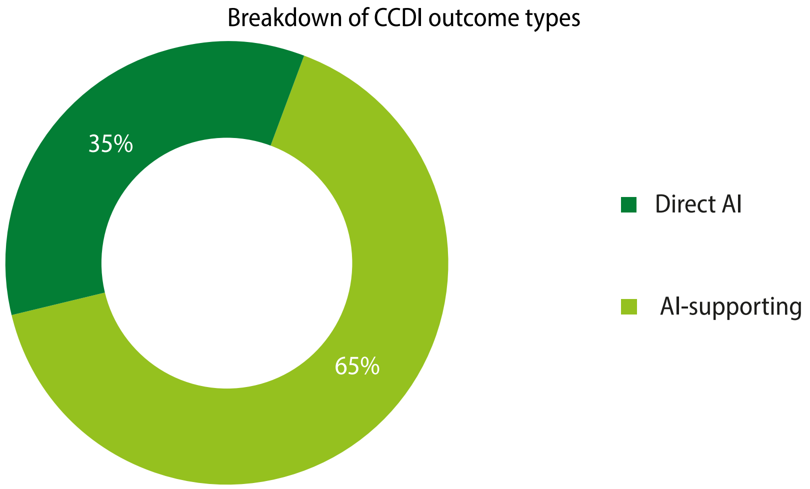
Figure 4.9. Percentage of alignment between the CCDI curriculum outcomes and those defined in the UNESCO framework



Data Source: Ministry of Education, UAE, 2023

The division of the CCDI curriculum into AI-supporting and direct AI outcomes, shown in **Figure 4.10**, reveals a promising trend toward adopting and integrating AI in education. Direct AI outcomes are those that significantly impact students' learning through AI technology as the primary means to achieve the intended aims. As these account for 65 per cent of the outcomes, it seems that schools are investing in applying and implementing AI solutions to provide students with customized learning experiences that cater to their unique needs and learning styles, potentially resulting in better academic outcomes and increased engagement. The remaining 35 per cent of outcomes are AI-supporting, meaning they are not directly related to AI but support its implementation and adoption in the education sector. This suggests that there is recognition of the potential for AI to enhance existing processes and workflows, and the balance between direct and supporting outcomes showcases a comprehensive approach to implementing AI in education in the UAE.

Figure 4.10. Proportion of direct AI outcomes versus AI-supporting outcomes in the CCDI curriculum mapping

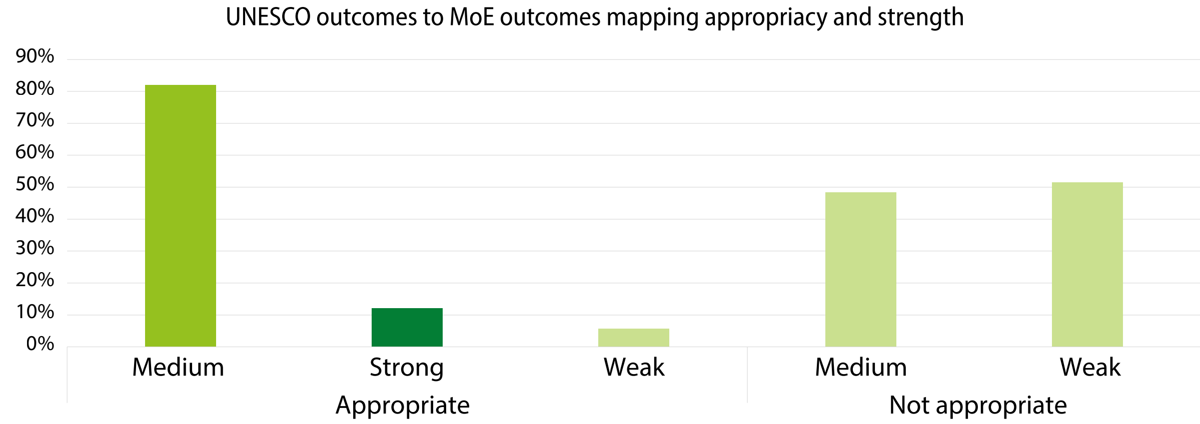


Data Source: Ministry of Education, UAE, 2023

Figure 4.11 illustrates the mapping of the CCDI learning outcomes to those in the *K-12 AI curricula* report (UNESCO, 2022) based on the framework mentioned in section 4.2. It reveals some positive findings on the integration of AI in schools across the UAE. Most outcomes (83 per cent) are appropriate (i.e. they have relevance and can offer good-quality learning experiences for students). Aligning outcomes with global goals improves learning and provides a more fulfilling educational experience. Moreover, medium-strength outcomes are found in 82 per cent of the CCDI, indicating that these outcomes have the potential to be strengthened to better align with UNESCO goals. This suggests that the UAE's education system has a significant foundation to build upon. Furthermore, 12 per cent of outcomes are categorized as strong, meaning that they not only align but are also highly likely to support the achievement of these global goals. This highlights that the CCDI curriculum is well positioned to contribute to the international effort to promote education and sustainable development, further enhancing the positive impact on students and the education system.

However, identifying weaknesses is also vital. The analysis found that 52 per cent of outcomes were not appropriate, which points to a need for greater alignment with UNESCO's goals. This does not imply that the CCDI outcomes are inadequate, but that there is room for improvement. Adopting more of the UNESCO outcomes' wording could provide a clearer and more consistent framework for these learning outcomes. This, in turn, could make tracking students' progress toward global education goals easier and ensure that the UAE's school system contributes to the broader sustainable development agenda. Also, the CCDI designers can explore opportunities for professional training and support for teachers across the country that equips them with the necessary knowledge and skills to teach consistently to global standards. These findings show that the MoE's education system is progressing in preparing students to meet challenges in the field of AI, but there is a need to enhance the appropriacy of learning outcomes and further align with UNESCO's goals.

Figure 4.11. Appropriacy and strength of the CCDI outcomes when mapped to UNESCO's AI framework



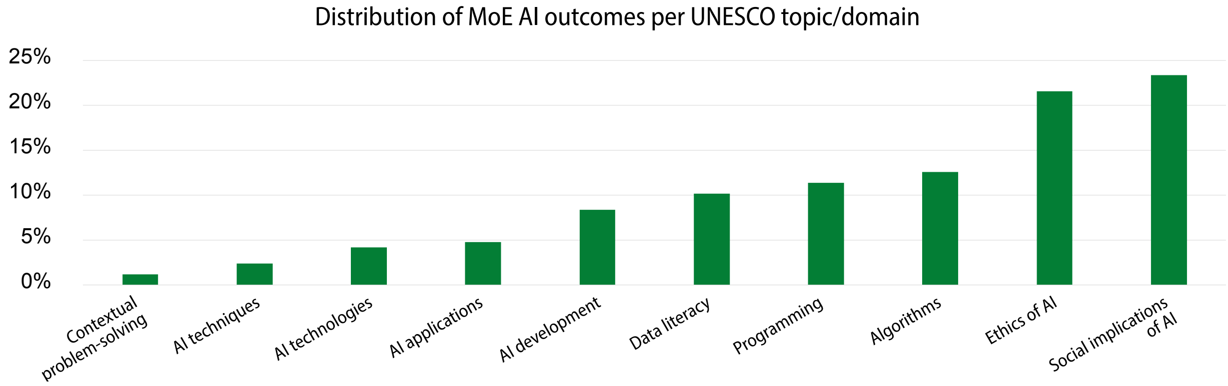
Data Source: Ministry of Education, UAE, 2023

The distribution of the CCDI curriculum's AI outcomes across various UNESCO topics and domains demonstrates a commitment to providing students with a strong foundation in AI and its applications. As shown in **Figure 4.12**, substantial percentages of learning outcomes are allocated to the ethics of AI (22 per cent) and social implications of AI (23 per cent). This indicates that the MoE values fostering a culture of responsible AI development and usage, equipping students with the skills and knowledge necessary to become more discerning consumers and developers of AI, and the technical skills to build and implement AI systems. The attention to social implications also demonstrates a commitment to ensuring that students understand the potential for AI to exacerbate existing social inequalities, as well as the need to develop AI systems that are inclusive and accessible to all. In doing so, the CCDI curriculum is helping to create a generation of AI developers and users who prioritize social responsibility and inclusivity.

The allocation of learning outcomes to algorithms (13 per cent) and programming (11 per cent) highlights a dedication to providing students with a strong foundation in computational thinking (Lodi and Martini, 2021), problem-solving and logical reasoning, all critical skills in a world increasingly dominated by technology. Students will be better equipped to tackle complex problems and develop innovative solutions by developing a deep understanding of algorithms and programming. Moreover, the learning outcomes on data literacy (10 per cent) are crucial for students to understand how to collect, manage, analyse and interpret data to derive insights and make informed decisions. This skill is particularly crucial in health care, finance and marketing.

While lower allocations were found for AI development (8 per cent), AI applications (5 per cent), AI technologies (4 per cent), AI techniques (2 per cent) and contextual problem-solving (1 per cent), it is important to note that these are specialized topics that may require advanced knowledge and resources. For example, AI techniques require a strong foundation in mathematics and computer science, while contextual problem-solving necessitates a deep understanding of both AI and the domain in which it is being applied. Similarly, AI technologies demand a robust understanding of hardware and software and may be covered in more specialized courses or engineering or computer science programmes. Thus, these can perhaps be areas to attend to in future revisions of the curriculum. Overall, the CCDI's allocations of AI-related outcomes reflect a commitment to giving students the skills and knowledge to succeed in a world increasingly dominated by AI.

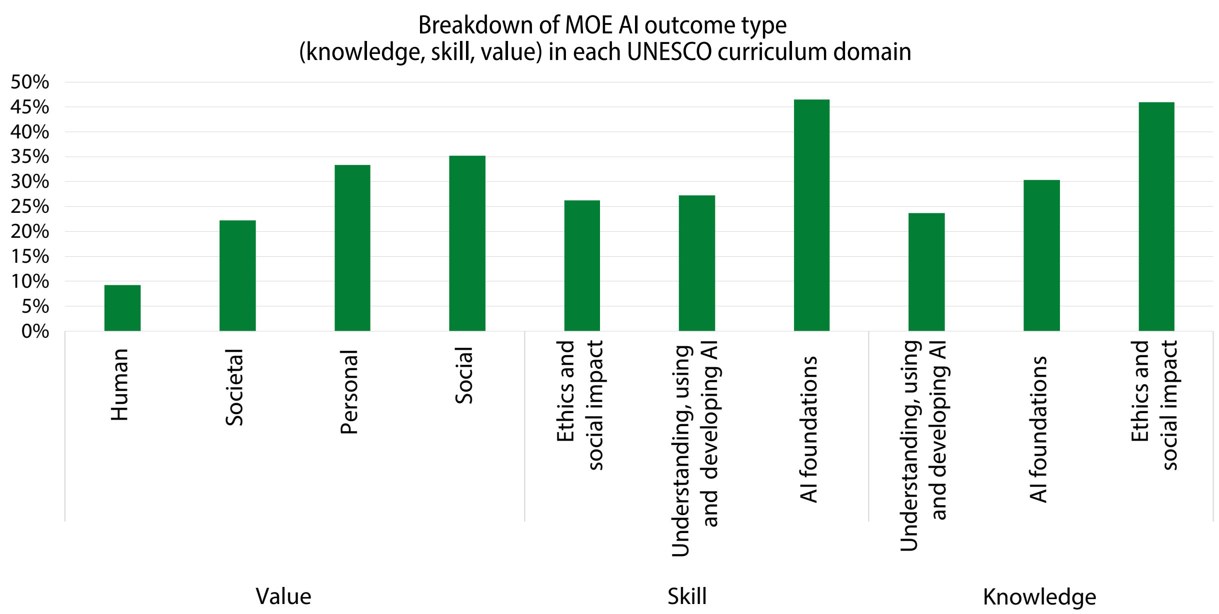
Figure 4.12. Distribution of all AI-related learning outcomes in the CCDI curriculum across the UNESCO domains



Data Source: Ministry of Education, UAE, 2023

The data shown in **Figure 4.13** highlights the CCDI designers' commitment to providing a well-rounded education that emphasizes knowledge, skills and values related to AI. Encouragingly, nearly half of the outcomes are related to knowledge, indicating that the curriculum imparts a solid understanding of AI foundations, use, development, ethics and social impact. The emphasis on ethics and social impact in the categories of knowledge (46 per cent) and skill (26 per cent) implies that the MoE recognizes the importance of considering the potential implications of AI on society and is taking proactive steps to ensure that students are equipped to do the same. The fact that over a third of the outcomes are related to skills (34 per cent) further underlines the MoE's emphasis on practical application and real-world readiness. Skills linked to AI foundations, ethics and understanding/developing are all strongly represented, pointing to the MoE's comprehensive approach to skill-building in the field of AI. The curriculum also emphasizes human values (9 per cent) and personal, social and societal values (33 per cent, 35 per cent and 22 per cent, respectively), thereby educating students on the impact of AI on individuals, communities and society as a whole. This emphasis on values underscores the MoE's dedication to producing well-rounded, responsible citizens who are capable of navigating through an increasingly AI-driven world.

Figure 4.13. Distribution of CCDI outcomes in each category of the UNESCO framework grouped by type (knowledge, skill or value)

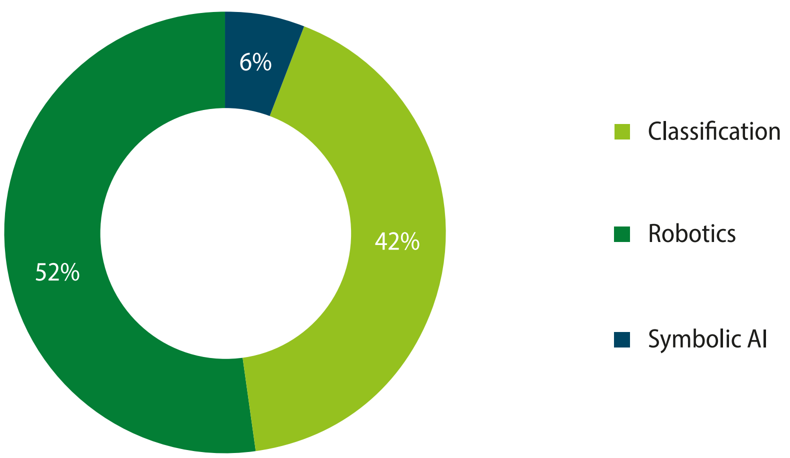


Data Source: Ministry of Education, UAE, 2023

Figure 4.14, displays the three AI types that feature the most in the CCDI curriculum's outcomes and content: robotics, classification and symbolic AI. Robotics, occupying 52 per cent, is an AI type that involves creating machines that can perform tasks autonomously or with minimal human intervention. This high percentage indicates the growing interest in developing intelligent machines that perform human-like tasks such as manufacturing, logistics, health care and transportation. The second most featured AI type is classification, accounting for 42 per cent. It uses machine-learning algorithms to categorize data into predefined groups (Sarker, 2021). This AI type is increasingly exploited in agriculture (Banerjee et al., 2018), health care (Jiang et al., 2017), and finance and business (Akerkar, 2019) to identify patterns, trends and anomalies in data. This information can then be used to make informed decisions and predictions.

Symbolic AI takes up 6 per cent of the CCDI curriculum's content and outcomes. It involves developing systems to understand and manipulate symbols and rules to represent and process information. Despite the relatively low percentage, symbolic AI remains relevant in various fields, such as NLP (Allen, 2003), expert systems and robotics (Mubin et al, 2013). In conclusion, this chart showcases the growing interest in robotics and classification and the continued relevance of symbolic AI in various fields. Understanding these AI types and their applications is crucial in developing and implementing effective AI solutions in different industries.

Figure 4.14. All AI types (technologies) that are sufficiently featured in the content and outcomes of the CCDI curriculum



Data Source: Ministry of Education, UAE, 2023

The data presented in **Table 4.4** provides valuable insights into the time allocation for these technologies and other topics in the CCDI curriculum as compared to the average time allocation internationally, reported by the sample of 21 respondents in the K-12 AI curricula report (UNESCO, 2022).

The second column indicates the time that the CCDI curriculum allocates to each AI topic or domain, measured in hours. Our analysis aggregates the time spent on each lesson based on the alignment of its outcomes to the ones in the *K-12 AI curricula* report (UNESCO, 2022). The next column shows the number of countries in the UNESCO statistics for which time allocations are available. The fourth column gives the maximum number of hours allocated by any country for the corresponding AI topic or domain, while the fifth column indicates whether the CCDI time allocation falls within the range of time allocations reported by other countries for the same AI topic. The sixth column shows the average time allocation for the AI topic across all the countries in the UNESCO data, and then the seventh column shows the median time allocation for the AI topic or domain across all the countries. Finally, the last column shows the difference between the CCDI's time allocation and the average across all the countries in the *K-12 AI curricula* report.

The curriculum is well rounded and allocates significant time to an array of AI-related topics, with algorithms and programming receiving the highest allocation at 111 hours and data literacy at 84 hours. This is commendable as it provides students with a strong foundation in the technical aspects of AI. The CCDI curriculum's allocation of time to ethics and the social implications of AI is also promising and reflects the UAE's commitment to the responsible and ethical development and use of AI. Furthermore, these data suggest that the CCDI curriculum responds to the AI industry's rapidly changing demands. This responsiveness is reflected in the significant time allocation to AI technologies (42 hours), demonstrating AI's importance in various industries, and contextual problem-solving (12 hours), a crucial skill for AI professionals. There is arguably a need to devote further hours to certain areas, such as ethics and social implications; however, on the whole, students will graduate with a robust foundation in data literacy, algorithms and programming which will prepare them for future careers in AI. In sum, the CCDI curriculum has a strong emphasis on technical knowledge and ethical considerations, and is responsive to changing demands. It gives students ample opportunities to learn about data and its role in AI applications so that they can make informed decisions and contribute positively to the AI industry.

Table 4.4. Time allocations per AI topic or domain in the UAE's CCDI framework compared to those of the curricula in other countries reported in the UNESCO statistics

AI topics or domains	CCDI time allocation in hours	No. of countries	Max hours	Within range	Average times	Median times	Diff.
AI development	21	6	30	Yes	12	11	9.3
AI techniques	45	18	128	Yes	17	6	28
AI technologies	42	12	305.5	Yes	37	11	5.1
Algorithms and programming	111	19	269	Yes	55	11	56
Applications of AI to other domains	6	18	92	Yes	11	8	-4.8
Contextual problem-solving	12	14	198	Yes	43	19	-31
Data literacy	84	17	78	No	27	26	58
Ethics of AI	90	17	54	No	13	6	77
Social implications of AI	27	12	78	Yes	14	7	13

Data Source: UNESCO, 2022; Ministry of Education, UAE, 2023

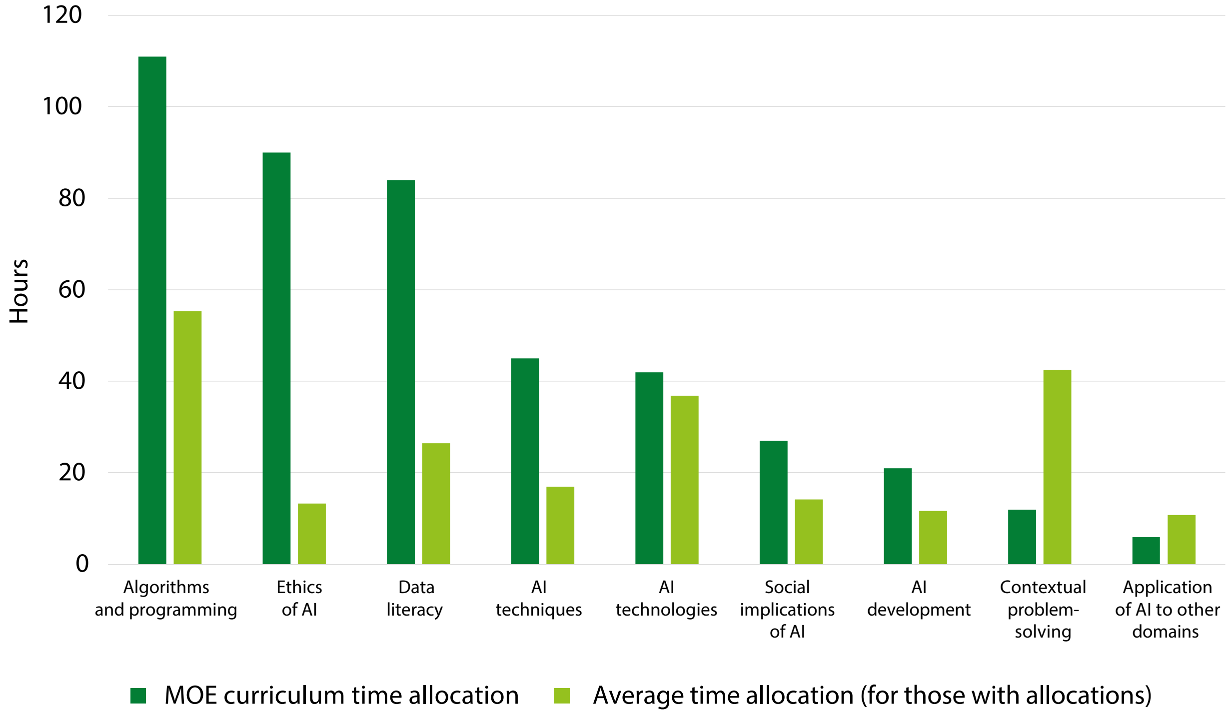
The comparison of time allocations for AI topics in the CCDI curriculum versus the international average, illustrated in **Figure 4.15**, shows that the former places a higher emphasis on technical skills and ethical considerations. The significantly higher time allocation for AI development, techniques and technologies in the CCDI curriculum indicates that it prioritizes students' learning of the fundamental aspects of AI, including how to design and implement AI systems. Additionally, the CCDI's considerably larger allocation of time for algorithms, programming and data literacy as compared to the average for the other countries shows that this curriculum aims at equipping students with the necessary technical skills for working with AI systems and extracting insights from large data sets to make informed decisions. This is a critical skill in the age of big data.

The CCDI curriculum also prepares students to be responsible users of AI by allocating substantial time to ethics and social implications. This is particularly important given considerations around the privacy, security and transparency issues raised by AI (Zafari et al., 2022). The CCDI is thereby helping students to understand the potential impact of AI on society and to develop the skills needed to navigate complex ethical dilemmas in the future.

While the CCDI's allocation for contextual problem-solving is less than the average, it still provides a well-rounded education on AI. Other institutions prioritize contextual problem-solving to teach students how to apply AI to real-world problems. However, the CCDI curriculum's focus on technical skills and ethical considerations ensures that students have a strong foundation to tackle contextual problem-solving in the future.

In conclusion, the CCDI time allocation for AI topics/ domains highlights its commitment to preparing students for the future of AI. It supplies students with a solid foundation in the knowledge and skills to work responsibly with AI systems by prioritizing technical skills, data literacy and ethical considerations, so that they can apply their learning to address real-world problems

Figure 4.15. Time allocations of the CCDI curriculum compared to international averages



Data Source: Ministry of Education, UAE, 2023

5. Delivery approach

5.1 Teacher training and support

Since teachers are the key agents responsible for checking whether AI learning outcomes are met by students, it is important to examine and review how teachers are trained and supported to deliver the CCDI curriculum. The training plans for the academic year 2021/22 include general descriptions of three-day workshops, which are provided before the start of each term, totaling nine days of workshops across the academic year. However, no data was found on the number of teachers who attended (or planned to attend) the workshops, or the time allocation for each subject. The CCDI training plans that appear for 2021/22 contain the following AI-related subjects:

9. Teacher-training programme offered in Term 2:

- Day 1: Artificial intelligence II - Concepts and methods, ways to achieve AI
- Day 2: Artificial intelligence II - Understanding neural networks, ways to achieve AI
- Day 3: Neural networks using Python

10. Teacher-training programme offered in Term 3:

- Day 1: Functional and structural components of a robot and AI in robotics
- Day 2: Intro to robotics, AI and ML; AI concepts; and Smart cities
- Day 3: Creating a robotic arm; AI and ML, neural networks I; Creating an autonomous vehicle control circuit and smart city solution

The Professional Development Training Plan document (2022) states that the teachers' training plan included the following related two-hour workshops on 13 December 2021:

- Robotics and programming workshop for cycle 1
- AI – neural networks workshop for cycle 3

The preparation of teachers to deliver lessons in AI-related subjects competently is a crucial prerequisite for successful education in the technological world. In providing ecologically valid AI education programmes for K-12 settings, teachers' perspectives should be considered so that their valuable insights and perceptions of AI can be incorporated (Yau et al., 2023). Teachers require proficiency in problem-solving, reasoning, perception and applied mathematics, as well as cognitive, psychological and ethical aspects related to artificial intelligence (Mahon et al., 2023). Therefore, there is a need for a robust strategy to upskill existing teaching staff by leveraging AI training initiatives or programmes and adopt AI to support pedagogical processes. While national governments promote the rollout of AI curricula by developing resources and setting standards, they must also supply teacher training and support as critical components of successfully implementing AI education for K-12 students. The six key considerations for this training and support are as follows:

- Knowledge and skill development: Teachers need to develop their understanding of AI concepts, technologies and pedagogies. They may need training in coding and data science, and instruction on teaching AI concepts to students at different grade levels.
- Professional learning communities: Teachers should have opportunities to collaborate with other educators within and outside their schools. This can include attending conferences and workshops or participating in online communities of practice.
- Access to resources: Teachers must access high-quality curriculum materials, including lesson plans, assessments and instructional videos. Such resources can be provided by industry partners such as IBM, Amazon, Microsoft and others. Some partners have also produced manuals, facilitator handbooks and case studies on AI at varying levels. Teachers should also have access to software and hardware tools, such as programming environments and robotics kits (Williams and Breazeal, 2020) that will allow them to teach AI concepts effectively.
- Mentoring and coaching: Teachers should have the chance to be mentored and coached by experienced AI educators, both during the initial implementation of the curriculum and as ongoing support throughout their teaching career.

> Supportive school and leadership: Teachers will need support from their administrators and leaders to effectively implement the CCDI curriculum. This may include providing resources for professional development, allocating time for curriculum development and implementation, and creating a school culture that values innovation and experimentation.

- Ongoing evaluation and improvement: Finally, teachers will need ongoing feedback and evaluation of their teaching practices and student learning outcomes, as well as opportunities for continuous improvement and professional growth. This may involve periodic assessments of student learning, peer evaluations and self-reflection.

5.2 Learning tools and environments

Simulation tools serve as a platform or medium through which pedagogical techniques and methodologies can be applied. They provide a virtual environment or representation of real-world scenarios. The pedagogical aspects come into play when educators design and utilize these tools within a larger instructional framework.

With the rapid advancement of technology, students must have access to the latest tools and digital resources. Using simulations, programming tools and online resources can give them a more engaging and interactive learning experience to help them better understand complex concepts. The appropriate learning tools and environments for teaching AI to K-12 students depend on the age of the students, their prior knowledge and experience with AI, and the curriculum's specific learning outcomes. Creating courses for machine learning using STEM-based robotic tools is an essential requirement that adds to the student's perception (Karalekas et al, 2023). The CCDI curriculum leverages existing environments and tools, engaging a range of free products such as Code.org, Scratch, Microsoft-AI and Machine Learning for Kids. Other tools include AI Robotic Kits, such as Magkinder Labeeb, Fateen, Maker Robotics Car and Raspberry Pi, which are used in various AI projects as recommended by Williams and Breazeal in 2020. These tools are used to train different models, understand machine learning algorithms and complete online tasks related to AI. Students in higher grades learn the Python language and use it to implement a variety of algorithms while utilizing ML libraries such as Scikit-learn.

Simulations can be a valuable tool for teaching AI concepts and skills in the classroom, supplying students with a safe and controlled environment for students to experiment with different algorithms, test various scenarios and explore real-world data. Using simulations may also enhance learning and engagement (Williams et al., 2021), help to make abstract concepts more tangible and provide visual representations of complex systems. Many types of AI simulations are available, ranging from simple ones demonstrating basic concepts to more complex ones requiring students to design and program their own algorithms. Some recommended AI simulation tools include Algodoo, Scratch, TensorFlow Playground, Cozmo, Code.org AI Activities, MIT App Inventor, Teachable Machine and AI Experiments. Of course, we do not need to use all these tools. The choice should be driven by what best meets the learning needs and goals of the students in question. Instructors could even select just one or two tools to focus on, allowing for a more in-depth understanding of each platform; the tool is less important than the learning outcomes it supports. Simulations can also facilitate critical thinking and collaborative learning, allowing students to develop and test AI models. In addition, they can provide more interactive and engaging assessments of AI skills than traditional tests and quizzes.

In terms of delivering the CCDI curriculum, some additional learning tools and environments that could be tailored to each cycle are listed below. Incorporating some of these tools could give students a wider array of resources so that they can engage with AI concepts more deeply and practically. By diversifying the educational tools and environments, teachers can further stimulate student interest, cater to different learning styles, and equip students with hands-on experience that is crucial for a comprehensive understanding of AI.

Cycle 1:

- Chatbots and voice assistants, and their everyday applications and underlying AI concepts, introduced via classroom discussions and presentations.
- Interactive whiteboards and projectors to display multimedia content such as videos, images and diagrams.

Cycle 2:

- Augmented reality and virtual reality tools and applications that can provide immersive experiences and enhance student engagement.
- Simulations and virtual environments such as OpenAI Gym, Unity and AirSim.

Cycle 3:

- Collaborative software such as GitHub, Google Docs and Slack to facilitate group projects and team collaboration.
- Cloud-computing platforms such as Amazon Web Services and Microsoft Azure to access computational resources and run machine-learning models.

6. Curriculum relevance and effectiveness

This chapter explains the benchmarking of the CCDI curriculum against other countries' K-12 AI curricula and practices, and the assessment of how the CCDI prepares and motivates students to pursue higher education in AI-related areas. Reputable job sites were surveyed to extract market needs and cluster AI-related competencies. Finally, the chapter identifies areas for improvement based on the analysis and feedback on the CCDI's relevance and effectiveness.

6.1 Comparing AI in the CCDI curriculum against other K-12 curricula

The incorporation of AI into pre-university education has been approached from various viewpoints, with the most comprehensive and ambitious being the development of full-scale AI literacy for future generations. According to Long and Magerko (2020), AI literacy involves the competencies necessary for individuals to critically assess AI technologies and effectively communicate and cooperate with AI. Policy-makers, educational institutions and researchers around the world strive to create guidelines that can be universally applied across all school systems (Vuorikari et al., 2022; Ng et al., 2021).

In lower grades, curriculum development initiatives represent a more specific level of approach within the scope of AI education. These initiatives aim to integrate AI instruction at certain stages of education stages (Yang, 2022; Lee et al., 2021; Chiu et al., 2022), assuming these would contribute to a broader digital or AI literacy framework. However, finding uniform strategies that can be implemented globally is challenging due to the varying structures of pre-university education systems worldwide. A notable effort in this area is the *K-12 AI curricula* report (UNESCO, 2022), whose goal is to shape the future of policies, national curriculum designs, institutional study programmes and strategies for developing AI competency.

The secondary level, catering to students aged 15-18, has been a major focal point for AI education. This age group often possesses the necessary digital and mathematical competencies for AI learning, enabling quicker results. Several noteworthy government-led initiatives exist in this realm, including in Australia, China, India and Republic of Korea, all of which have begun incorporating AI into their secondary school curricula. These programmes are often spearheaded by computer science and AI specialists and are largely modelled after AI courses and literature from university-level courses. A potential issue, however, is the critical role of secondary school educators in successfully implementing an AI curriculum.

One standout initiative is the US-based AI4K12 project,[2] launched in 2018 and run by the Association for the Advancement of Artificial Intelligence (AAAI) and Computer Science Teachers Association. It has developed the 'Five Big Ideas in AI' framework, which covers perception, representation and reasoning, learning, natural interaction, and societal impact (AI4K12, 2023). Comprised of global experts from various fields within computer science and education, its goals include formulating national AI teaching standards and developing an online directory of AI resources and tools for K-12 students.

Another recent initiative is the AI+ project,[3] the European Erasmus+ scheme to introduce AI in the high school curriculum. It is spearheaded by the University of Coruña in Spain and involves collaboration with six high schools across five European countries. The teaching units that form the curriculum are original materials developed by educators, which have been field-tested by student groups from the participating schools to create a robust curriculum to be introduced in European schools from the 2022/23 academic year. The participating countries and institutions are: Spain (*CPI A Xunqueira* and *IES David Buján*), Italy (*2IIS A-Ruiz*), Slovenia (*Solski center Velenje*), Lithuania (*Všl Panevė˙žio profesinio rengimo centras*) and Finland (*Joensuun yhteiskoulun lukio*).

For an appropriate comparison of the CCDI curriculum with international K-12 AI curricula (Yue et al., 2022), the CCDI was measured against both AI4K12 and AI+ as they are the two main programmes on which information is available in English.

2 See https://ai4k12.org
3 See https://aipudc.azurewebsites.net

6.1.1 Methodology

The methodology used in the mapping involved a comprehensive process of analysing the learning outcomes in the UAE's CCDI and those of the two selected AI initiatives. This process comprised the following five steps:

11. Understanding the frameworks: First, it is essential to thoroughly study all of the frameworks' learning objectives, goals and intended outcomes, which provide the foundation for the mapping process.
12. Categorization of learning outcomes: The CCDI learning outcomes are examined individually. Each outcome is studied to understand its key objectives and underlying principles.
13. Mapping outcomes to the selected framework: Each learning outcome from the CCDI curriculum is then matched to one of the main topics in the selected framework based on its content, objectives and underlying principles. This process involves an in-depth evaluation of the learning outcomes and the frameworks' main topics to support accurate mapping.
14. Iterative review: After the initial mapping, an iterative review ensures that each outcome correctly aligns with the appropriate topic. If an outcome can be associated with multiple topics, it is placed in the category that aligns most closely with its primary focus.
15. Identification of unmapped outcomes: Finally, any learning outcomes that do not map directly onto the frameworks' topics are identified. These outcomes usually involve areas like data management and collaboration, which, while important, may not fit directly into a specific AI topic.

This methodology facilitates a comprehensive and accurate mapping but it is important to note that any curriculum's real-world effectiveness also depends on its implementation, including teaching methodologies, assessment strategies and adaptation to individual learners' needs.

6.1.2 Analysis and results

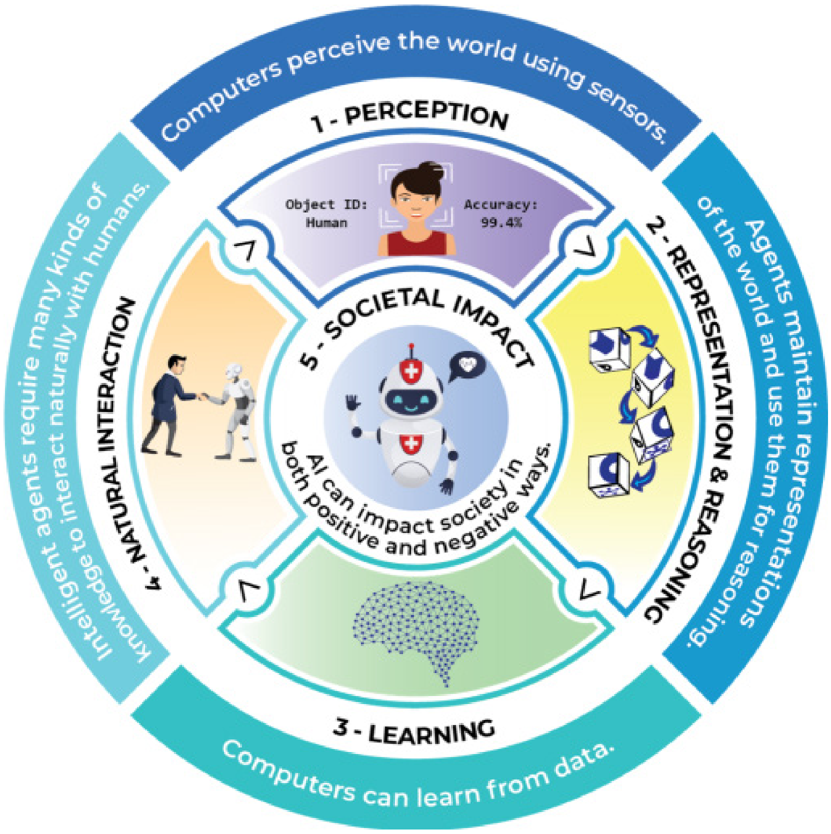
Comparing the AI4K12 with the CCDI curriculum

The AI4K12 framework is based on the 'Five Big Ideas in AI' (**Figure 6.1**), which as mentioned in section 2.3 includes perception (how computers process and interpret sensory data), representation and reasoning (how computers store and manipulate knowledge to make decisions), learning (how computers improve their performance based on data and experience), natural interaction (how computers communicate with humans in natural ways) and societal impact (the ethical, legal and social implications of AI). On the other hand, the CCDI curriculum is intended to equip students with skills in AI, machine learning, data analysis, robotics and programming, to give them the foundation for higher education in AI-related fields and satisfying job market requirements.

When comparing the AI4K12 framework to the UAE's curriculum, it is evident that both focus on providing students with a foundational understanding of AI concepts, tools and techniques. The AI4K12 is more of a guiding framework, while the CCDI is more structured and detailed, focusing on specific AI competencies and skills.

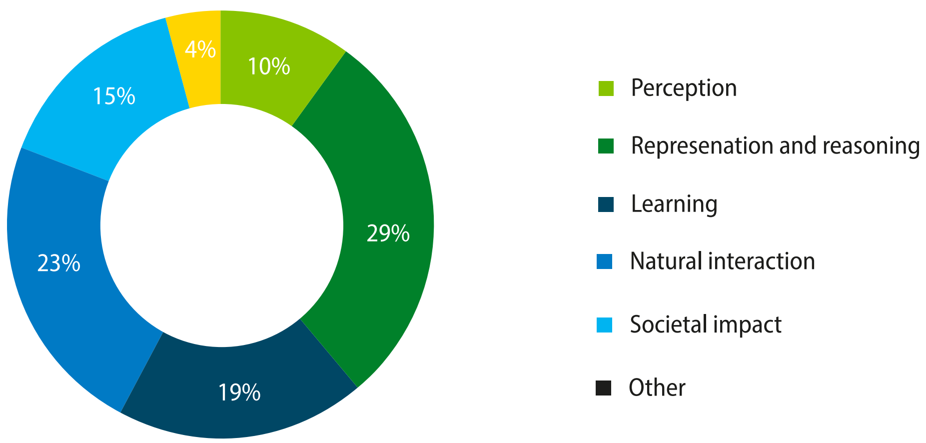
Figure 6.2 depicts the mapping of the CCDI outcomes to the AI4K12's Five Big Ideas, showing the percentage of outcomes related to each of the five areas. All areas are covered, and even the area with the smallest percentage, perception, accounts for one-tenth of the CCDI outcomes which is very much acceptable. However, a few outcomes from the CCDI were not possible to explicitly link to the AI4K12 framework. These primarily relate to collaboration skills. While such outcomes are not directly mentioned in the Five Big Ideas, the authors believe these concepts are crucial for effective teamwork in an AI-driven environment.

Figure 6.1. The Five Big Ideas in AI



Source: AI4K12, 2023

Figure 6.2. Percentage of CCDI outcomes that align with each of the AI4K12's Five Big Ideas in AI[4]



Data Source: AI4K12, 2023; Ministry of Education, UAE, 2023

4 When researching this report, the Five Big Ideas in AI were still in development. They have matured and feature comprehensive learning outcomes, constituting a recommended basis for future AI curriculum developers.

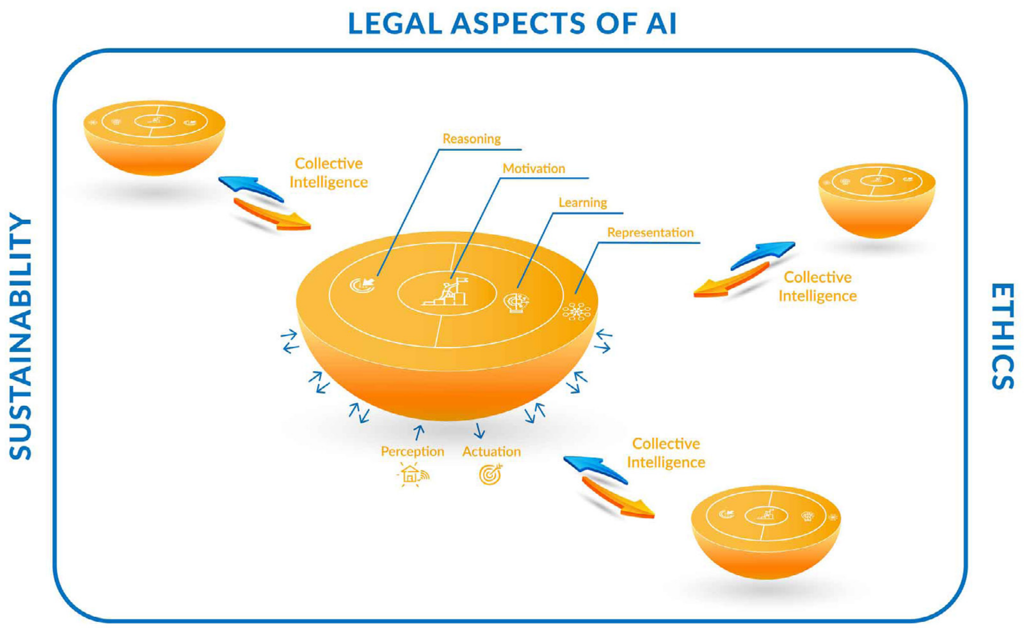
Comparing AI+ with CCDI

To determine the core AI concepts that pre-university students need to understand, AI+ took into account the topics outlined in 'AI Background'. As such, the AI+ methodology (A+, 2023) draws inspiration from the AI4K12 initiative while also introducing some alterations and expanding to eight major themes, which are:

1. Perception: This includes areas such as computer vision, speech recognition, tactile interaction and IoT-based remote sensing.
2. Actuation: This encompasses movement, speech production, information display and IoT-based remote actuation.
3. Representation: This covers topics like maps, mathematical models and memory.
4. Learning: This delves into supervised, unsupervised and reinforcement learning methods (artificial neural networks).
5. Reasoning: This involves planning, optimization and search methods.
6. Collective intelligence: This includes coordination, communications and IoT.
7. Motivation: This entails defining goals, autonomous design, human- machine interaction and learning through demonstration.
8. Sustainability, ethics and legal aspects: This covers considerations around bias and discrimination as well as data protection and privacy legislation.

Figure 6.3 gives a visual interpretation of the AI+ ecosystem,[5] built around these eight topics. Legal considerations, ethics and sustainability envelop the ecosystem due to their multifaceted relevance in AI. This ecosystem, depicted within the square, resembles a cellular system, with individual 'cells' symbolizing AI systems capable of communication within a certain 'fluid'. Each 'cell' or AI system in the diagram processes information from its surroundings (perception) and acts upon it (actuation). Within the 'cell', the AI+ team have devised a layered structure, with the outermost layer being the representation layer, followed by the learning layer, and then the reasoning layer. At the core, they have the motivation layer that governs the system's operations.

Figure 6.3. Main areas of the AI+ ecosystem



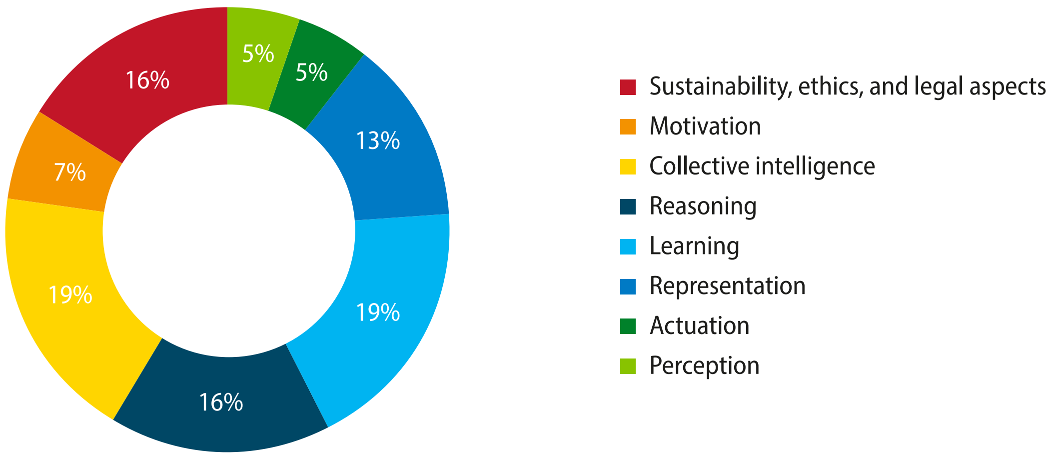
Source: AI+, 2023

5 See https://aipudc.azurewebsites.net/our-approach

Both the CCDI and AI+ initiative share the common goal of providing students with a solid foundation in AI concepts, ethical considerations and practical skills to prepare them for the challenges and opportunities presented by AI technologies in various fields. The mapping shown in **Figure 6.4** illustrates how the CCDI's learning outcomes align with the main topics of AI+. There is a distribution of outcomes across the topics, indicating comprehensive coverage of these areas by the CCDI curriculum. The lowest percentage is 5 per cent for both perception and actuation. In fact, because these two areas are very related and complement each other, this could be read as 10 per cent for a single domain, which constitutes a mapping rate that is more than acceptable.

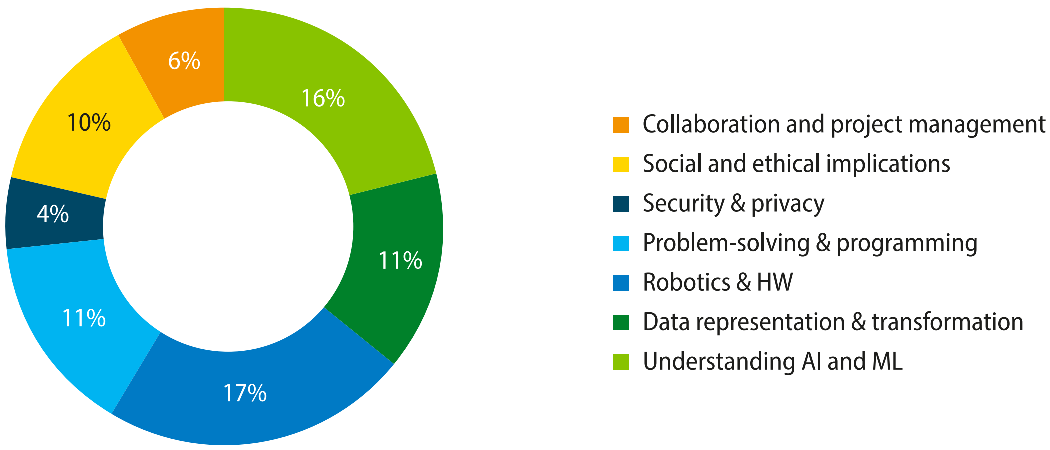
The CCDI learning outcomes were then categorized into broader areas, resulting in seven groupings, as depicted in **Figure 6.5**.

Figure 6.4. Percentage of CCDI outcomes that align with each of the main topics in the AI+ initiative



Data Source: Ministry of Education, UAE, 2023

Figure 6.5. Clustering CCDI learning outcomes into main topics



Data Source: Ministry of Education, UAE, 2023

The mapping of the CCDI's learning outcomes to the AI4K12 and AI+ initiatives demonstrates a close alignment in both cases. This process highlights the strong correspondence between the CCDI and the core concepts and topics emphasized in these prominent AI education frameworks. This suggests that students following the CCDI curriculum are exposed to the essential knowledge, skills and competencies required to understand and engage with artificial intelligence in a comprehensive and holistic manner. By aligning with these initiatives, the CCDI effectively prepares students to navigate the dynamic landscape of AI, fostering their critical thinking, problem-solving and ethical decision-making abilities.

6.2 Comparing the CCDI curriculum against higher education AI curricula

6.2.1 Methodology

This section aims to examine the extent to which the CCDI may prepare and motivate students to pursue higher education in AI-related areas by comparing it with the programme learning outcomes (PLOs) and course learning outcomes (CLOs) of some AI programmes in higher education. To evaluate the curriculum's relevance and effectiveness against higher education curricula, another mapping process was conducted, utilizing the internationally recognized ABET outcomes which have been collaboratively developed with esteemed professional societies like the IEEE (Institute of Electrical and Electronics Engineers) and ACM (Association for Computing Machinery). These outcomes, widely regarded as the gold standard, encompass a broad spectrum of engineering and computing programmes. Virtually all AI programmes at the university level map their CLOs to these outcomes. Hence, by mapping the CCDI outcomes to ABET's PLOs, the study team provided a template that allowed them to subsequently map each university's specific CLOs to the PLOs. This process ensured a low-resolution mapping from CCDI outcomes to university CLOs, taking into account the unique context, characteristics and requirements of each institution. Attempting to map CCDI outcomes directly to any university's CLOs would not adequately capture the essence of the topic and its rapidly evolving nature since some universities have AI integrated as a programme concentration, whereas others have it as a full programme. Moreover, the conclusions drawn from such an approach would be limited in scope. By adhering to the established mapping framework, the authors were able to ensure a comprehensive and robust evaluation of the CCDI curriculum's relevance and effectiveness in comparison to AI programmes offered in higher education.

The seven PLOs of the ABET programme, taken as the benchmark for evaluation, are:

PLO1. Application and problem-solving: An ability to identify, formulate and solve complex artificial intelligence problems by applying principles of engineering, science and mathematics.

PLO2. Design with constraints: An ability to apply artificial intelligence design to produce solutions that meet specified needs with consideration of public health, safety and welfare, as well as global, cultural, social, environmental and economic factors.

PLO3. Effective communication: An ability to communicate effectively with a range of audiences.

PLO4. Impact and responsibilities: An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental and societal contexts.

PLO5. Teamwork and leadership: An ability to function effectively in a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks and meet objectives.

PLO6. Critical thinking and experimentation: An ability to develop and conduct appropriate experimentation, analyse and interpret data, and use engineering judgment to draw conclusions.

PLO7. Lifelong learning: An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

The process involved identifying the relevant learning outcomes of the CCDI that correspond to each of the seven PLOs. After this mapping was completed, the alignment percentage for each PLO in the higher education programme was calculated by adding up the CCDI outcomes that map to it and dividing this by the total number of CCDI outcomes. This analysis provides a quantified measure of the alignment between the CCDI curriculum and the seven PLOs of ABET.

6.2.2 Analysis and results

The results of the mapping (**Figure 6.6**) show that PLO1 has the highest alignment percentage (47.3 per cent). This outcome focuses on teaching students how to identify, formulate and solve complex engineering problems by applying engineering, science and mathematics principles. This alignment indicates that the CCDI curriculum provides a solid foundation in the technical aspects of AI, which is essential for pursuing higher education in this field.

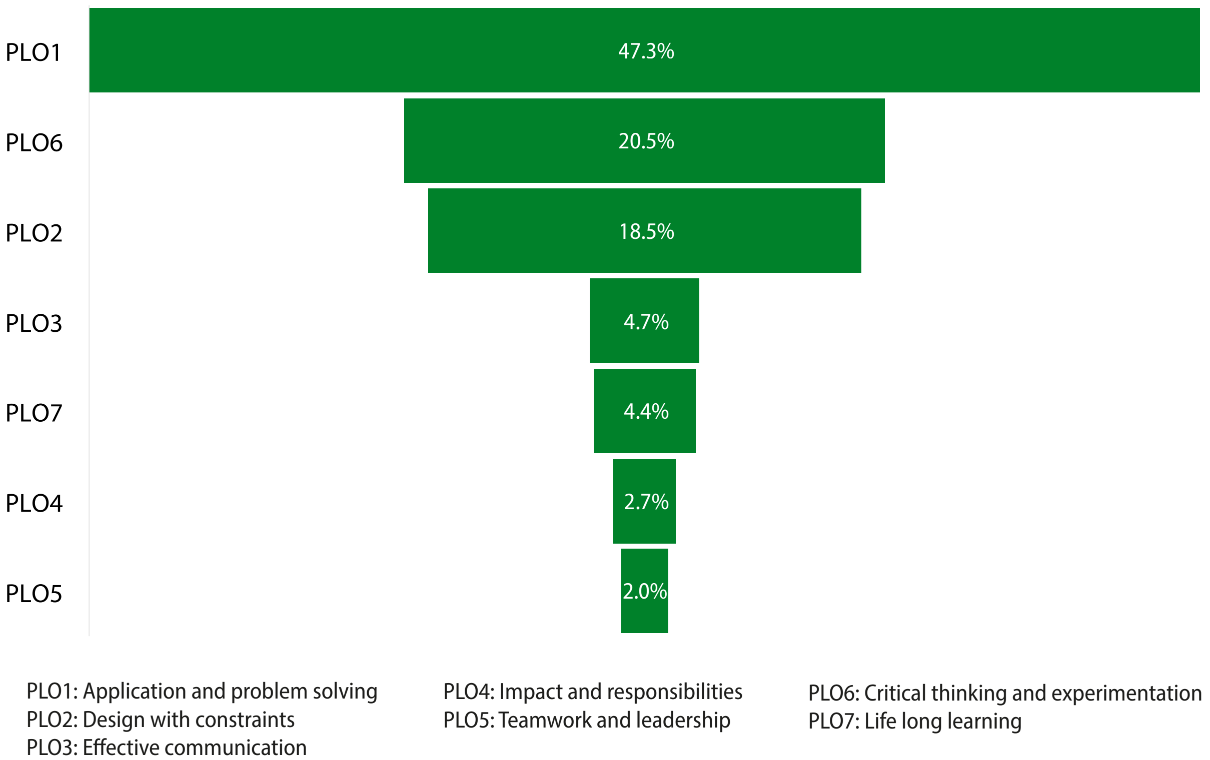
The curriculum is also strongly aligned with PLO6 (20.5 per cent), which focuses on developing critical thinking, problem-solving and analytical skills through experimentation, data analysis and engineering judgment. This alignment can further motivate students to pursue higher education in AI-related areas, and also suggests that the CCDI emphasizes practical skills and hands-on experience in AI, which is highly valued at university and in the workforce.

PLO2 likewise has a substantial alignment (18.5 per cent), indicating that the curriculum effectively teaches students how to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety and welfare, as well as global, cultural, social, environmental and economic factors. This means that students will be well prepared to design AI systems that meet key criteria with respect to their broader impact on society.

There are lower percentages of alignment for PLO3, PLO4, PLO5 and PLO7 (4.7 per cent, 2.7 per cent, 2.0 per cent and 4.4 per cent, respectively), pointing to possible opportunities to improve the CCDI by targeting these areas. PLO3 focuses on effective communication skills, PLO4 on recognizing ethical and professional responsibilities, PLO5 on teamwork, and PLO7 on the ability to acquire and apply new knowledge.

The analysis shows that the CCDI effectively prepares learners for higher education in AI-related areas by providing a strong foundation in engineering, science and mathematics, enabling students to identify, formulate and solve complex engineering problems. Additionally, the curriculum teaches students how to design AI systems that consider the broader impact on society, and develop critical thinking and problem-solving skills. Although there is room for improvement in certain areas, the curriculum aligns with the PLOs of higher education AI curricula, especially in technical skills, practical experience and ethical considerations.

Figure 6.6. CCDI outcomes mapped to ABET's programme learning outcomes for higher education



6.3 Comparing the CCDI curriculum against labour market needs

6.3.1 Methodology

To assess the alignment between the CCDI curriculum and the labour market demands in the UAE, the study adopted a comprehensive approach that integrated a job search, competency mapping and a curriculum review. For the job search, the study scanned 150 jobs across five websites (see **Figure 6.7**). The information collected for each job includes job title, emirate, competencies and job description. These data were then used for analysing the distribution of AI-related jobs across various sectors, emirates and job titles, and for competency mapping, identifying the essential skills and knowledge required for each job.

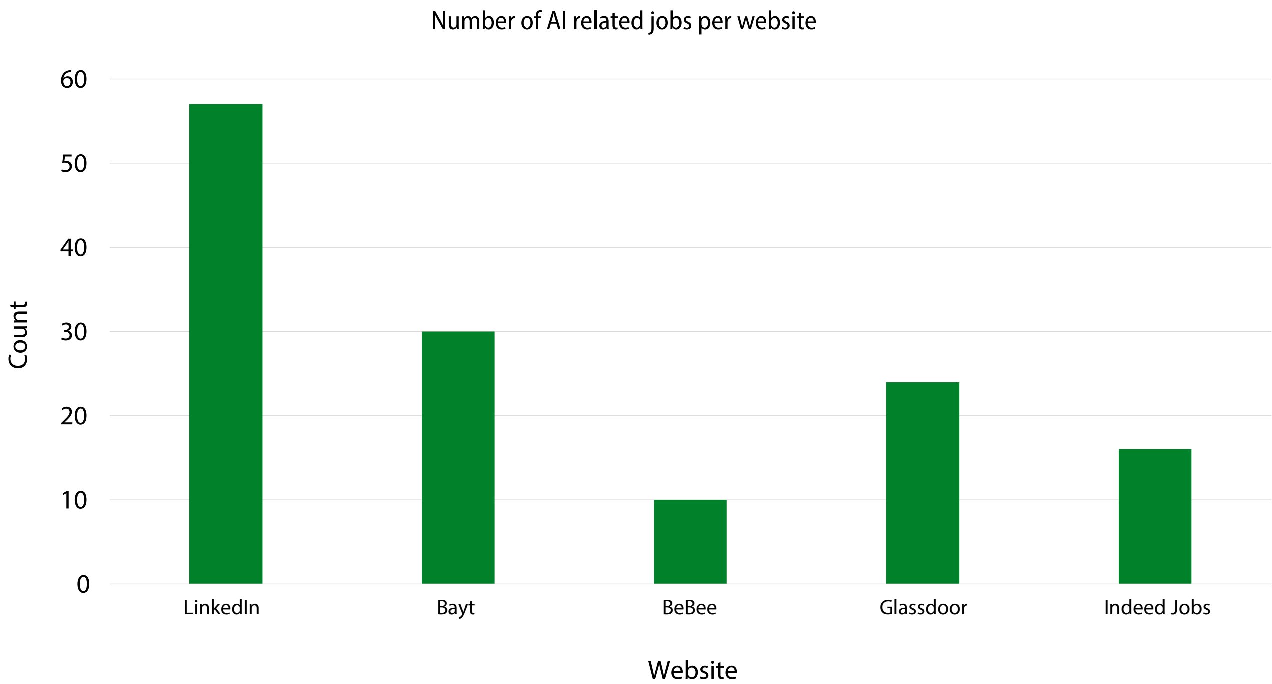
First, the job titles and descriptions were scrutinized by the study team to identify the most in-demand AI competencies, resulting in a list of 36 skills needed in the market.

Next, the team determined which competencies the CCDI outcomes covered and assessed their relevance to the job market. The percentage of jobs that required each competency was then calculated and these findings were compared to the previous CCDI mapping results.

After mapping these competencies, the jobs identified through the search were grouped based on their job descriptions and company information into industries to determine the distribution of AI-related jobs across various sectors. Subsequently, the percentage of such jobs in each sector was calculated. The distribution of the jobs across different emirates in the UAE was also analysed based on job location to compare the demand for AI-related skills by region.

The resulting competency framework was used to review the CCDI curriculum, highlighting areas where the curriculum aligned with or deviated from the needs of the labour market. Using a multifaceted approach, this methodology allowed for a comprehensive analysis of the CCDI's relevance and effectiveness in terms of preparing learners to enter the AI job market in the UAE.

Figure 6.7. Number of AI-related jobs in the UAE found per website



6.3.2 Analysis and results

Both strengths and areas for improvement have been highlighted in this assessment of the effectiveness and relevance of the CCDI and its outcomes with respect to the UAE's labour market. The assessment has highlighted the strengths and areas for the CCDI curriculum improvement. **Figure 6.8** presents a comparison of some AI competencies required by the job market and the CCDI's coverage of them. In particular, the team looked at the three job competencies that the CCDI covers most substantially, and the three areas where the CCDI curriculum most notably diverges from labour market needs.

One of the key strengths of the CCDI's learning outcomes is their focus on programming skills, the top competency demanded by the job market. Programming skills are covered by 16.7 per cent of the CCDI curriculum, almost double the demand in the job market (8.6 per cent). The strong coverage of these skills is important because programming languages are the foundation of AI and are used for building algorithms, models and applications.

Another strength of the CCDI outcomes is their focus on problem-solving and analytical skills (7.6 per cent), essential competencies for AI professionals. This proportion is 2.7 per cent higher than the demand of the job market. Problem-solving and analytical skills allow learners to build effective AI models that can solve complex problems, suggesting that the robust coverage of this competency in the CCDI means students will be well equipped to tackle real-world problems using AI.

Additionally, the CCDI boasts a relatively high coverage of knowledge of IoT (8 per cent). Such emerging technologies are increasingly being integrated with AI applications, turning this kind of knowledge and ability to leverage the potential of IoT into key assets for AI professionals.

Based on the above analysis, it is apparent that the CCDI aligns well with the demands of the job market in many areas, which is a testament to the high-quality education and training provided by the MoE. However, as with any curriculum, there is always scope to improve. The job market requires skills in data analytics at a rate of 7.1 per cent as it is becoming increasingly essential for building effective AI models that use large amounts of data, but the CCDI covers only about 4 per cent of this competency. Similarly, database and data warehousing are demanded by 6.3 per cent of the jobs surveyed, yet the CCDI outcomes cover it at just 2.4 per cent. Therefore, to ensure that the UAE's future AI professionals have a comprehensive skill set to excel in the job market, CCDI designers need to increase the emphasis on these competencies.

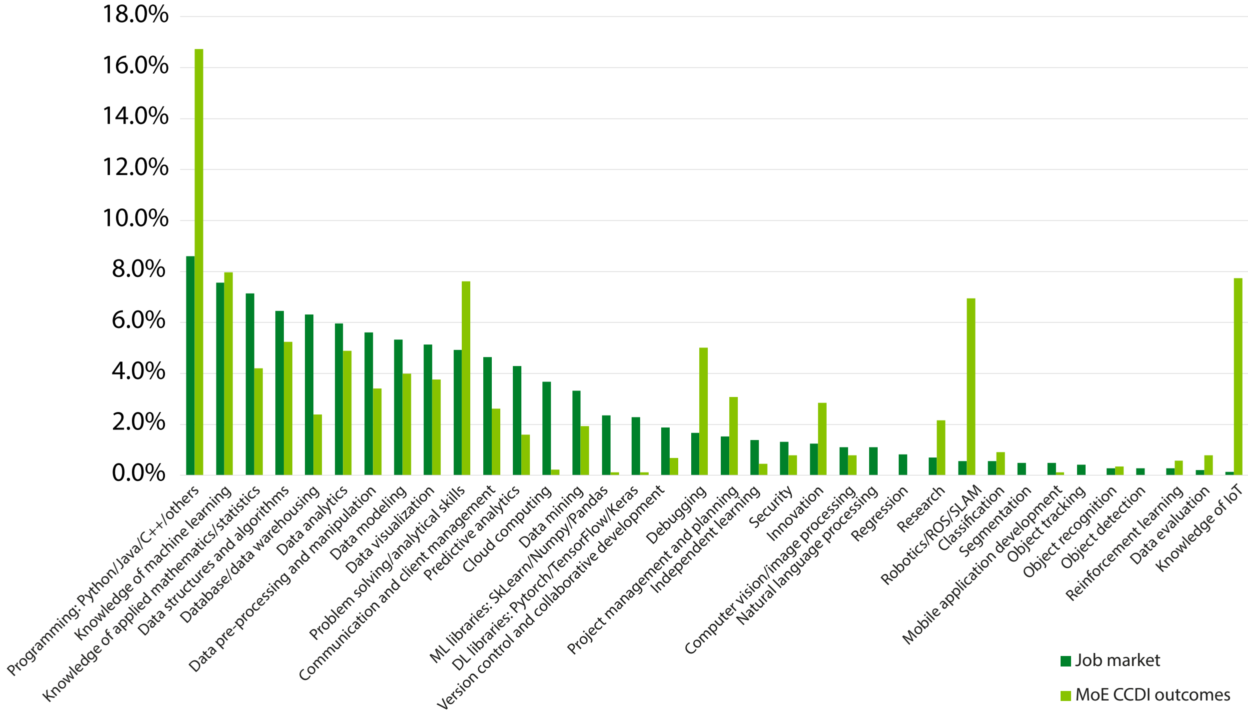
The coverage of some of the most in-demand skills related to using ML and DL libraries, such as SkLearn, Numpy, Pandas, PyTorch, TensorFlow and Keras, is limited to the cycle-3 content in the CCDI curriculum. One possible reason for this is that these competencies are advanced and may require more specialized training at the university level. Given that the CCDI is constantly evolving to keep up with the latest developments in the industry, there may be plans to incorporate these competencies in future updates.

Students must have a comprehensive understanding of these libraries as they are widely used in the industry. For the time being, to gain this understanding, learners need to seek additional resources or pursue specialized training outside the standard curriculum.

In summary, while the CCDI and its outcomes align well with the job market demands in some areas, there is room for improvement in certain areas, such as data analytics, database and data warehousing, and coverage of popular machine-learning and deep-learning libraries. Nevertheless, the strong concentration on key AI concepts and skills in the curriculum, along with the inclusion of relevant practical projects and activities, positions students well to enter the field of AI and contribute to the UAE's future economic ecosystem.

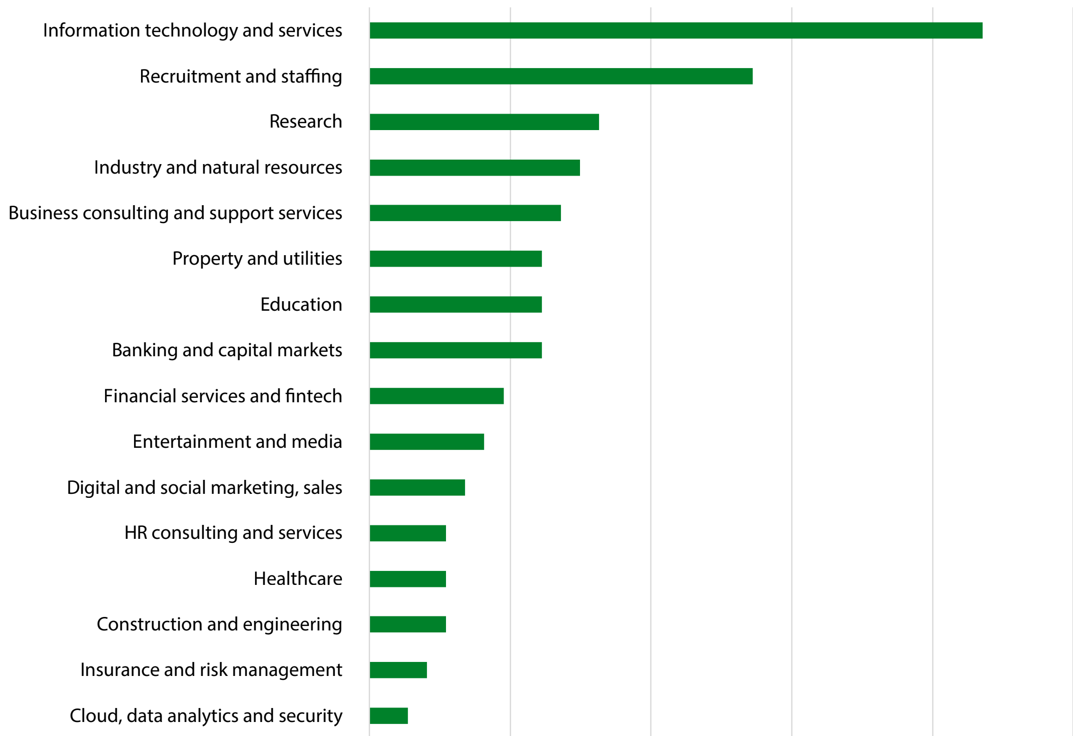
The distribution of AI-related jobs across various sectors in the UAE (**Figure 6.9**) shows that the information technology and services sector has the highest percentage, accounting for 22 per cent of all AI-related jobs, indicating that students may benefit from prioritizing the skills required to work in this sector. However, other sectors also offer good opportunities for students with AI-related skills and knowledge, such as recruitment and staffing (14 per cent); industry and natural resources (7 per cent); and business consulting and support services (7 per cent). On the other hand, some sectors, such as cloud, data analytics and security (1 per cent); entertainment and media (4 per cent); and health care (3 per cent), require more specialized and focused teaching of AI competencies than is offered by the CCDI curriculum.

Figure 6.8. Comparison between the competencies required in the AI-related job market and the coverage of the CCDI outcomes



Data Source: Ministry of Education, UAE, 2023

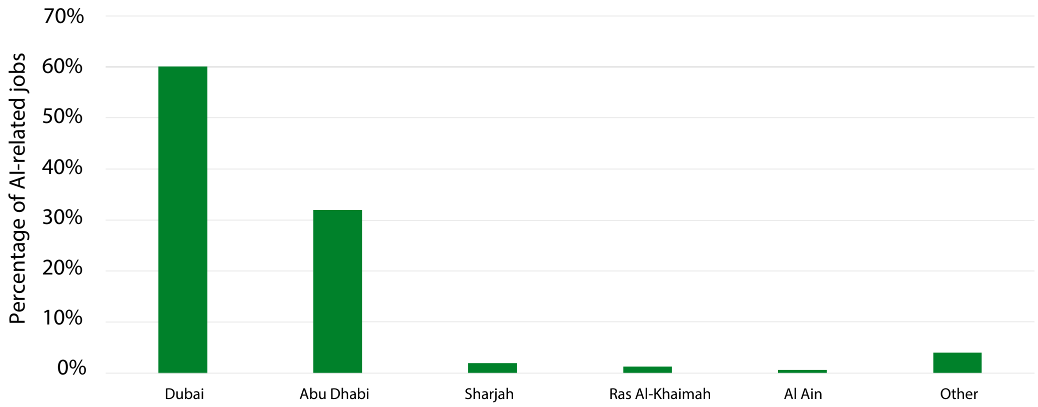
Figure 6.9. Distribution of AI-related jobs in the UAE across various sectors



Data Source: Ministry of Education, UAE, 2023

In addition to the sector-wide distribution of AI-related jobs, the UAE exhibits significant regional differences in the demand for AI-related jobs. As shown in **Figure 6.10**, Dubai has the highest percentage of AI-related jobs, accounting for 60 per cent of the market, while Abu Dhabi follows with 32 per cent. On the other hand, the remaining emirates, including Sharjah, Ras Al-Khaimah and Al Ain, collectively account for only 8 per cent of AI-related jobs. This may be due to factors such as the concentration of AI companies, level of government support, availability of infrastructure and proximity to major financial centres. Furthermore, Dubai has established itself as a central location for emerging technologies by implementing several initiatives such as the Dubai Future Foundation,[6] to attract and assist innovative technology companies. Abu Dhabi also emphasizes advancing its technology sector with initiatives like the Abu Dhabi Investment Office and the Abu Dhabi Global Market, which encourage innovation and entrepreneurship.

Figure 6.10. Regional distribution of AI-related jobs across the UAE

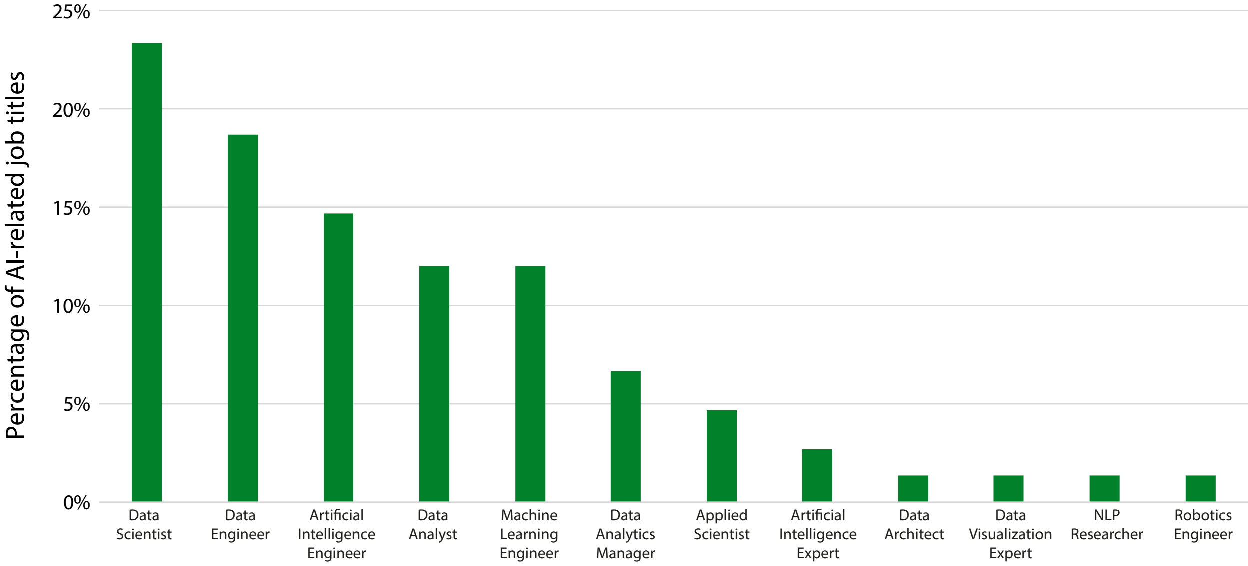


Data Source: Ministry of Education, UAE, 2023

Figure 6.11 provides insight into the most common job titles in the AI field, which can help explain the regional differences in regional distribution highlighted in **Figure 6.10**. The most frequent one is Data Scientist, representing 23 per cent of AI-related job titles. This role requires specialized data analysis, machine learning and programming skills for developing and implementing AI technologies. The second most common job title is Data Engineer (19 per cent), which involves database management, data warehousing and data-pipeline development skills. Artificial Intelligence Engineer is the third most common one, representing 15 per cent of AI-related job titles and highlighting the importance of teaching students fundamental concepts and technologies, such as deep learning, NLP and computer vision. Other job titles with notable percentages include Data Analyst (12 per cent) and Machine Learning Engineer (12 per cent), which require specific skills and knowledge relating to data visualization, feature engineering and model selection. The remaining job titles such as Applied Scientist and Data Architect account for less than 7 per cent of AI-related jobs each and necessitate more specialized research experience and capacities in algorithm design and hardware development.

6 See https://www.dubaifuture.ae

Figure 6.11. Market analysis of AI-related job titles in the UAE



Data Source: Ministry of Education, UAE, 2023

7. Key findings and recommendations

7.1 Analysis of the CCDI curriculum

7.1.1 CCDI curriculum content

Key findings

The CCDI curriculum is exceptionally forward-looking as it is designed to equip students with the latest knowledge and skills necessary to tackle the complex challenges of the future. The curriculum covers many topics, including robotics, embedded systems, electronics, programming, AI and machine learning, all rapidly evolving fields with immense potential for innovation and impact. It also emphasizes the importance of ethical considerations in developing and deploying AI systems, preparing students to navigate ethical dilemmas when using AI to solve real-world problems. By providing students with a cutting-edge education in AI, the curriculum ensures that they are well positioned to be at the forefront of the AI revolution and make significant contributions to society.

The document review reveals evidence of a spiral development approach where the content's depth gradually increases from one grade to the next. The main aim of this approach is to introduce AI to as many students as possible at an early stage. However, despite the many positive and commendable aspects of the CCDI curriculum, numerous opportunities exist to redistribute its content, reduce redundancy and improve the overall curricular topic flow. Reducing redundancy would create room for exploring other AI areas and improving the CCDI's alignment with UNESCO's framework. Redistributing the content can help ensure that all critical areas of AI are adequately covered in the curriculum and that students' knowledge of AI is well rounded. Furthermore, improving the overall curricular topic flow can give students a more coherent and structured learning experience, making it easier to connect different concepts and apply them in real-world scenarios. Such changes can also facilitate a more interdisciplinary approach to teaching AI.

Recommendations

1. Commission a future enhancement of the CCDI curriculum by redistributing curricular topics and reducing redundancies through spiral development. This will create more time for exploring other critical areas of AI while guaranteeing that all essential topics are adequately covered in the curriculum. In particular, the following action items are suggested:
   a. Establish a Curriculum Review Committee comprising experts from various fields to review the CCDI curriculum comprehensively. This diverse expertise ensures a well-rounded perspective on curriculum development, while the collaboration among experts fosters innovation and effective decision-making.
   b. Conduct a detailed analysis of the existing curriculum content, mapping the topics covered in each grade level and identifying redundancies and gaps. This analysis should aim to provide a clear understanding of the current content distribution, identify areas requiring improvement, and enable efficient utilization of instructional time by addressing redundancies and focusing on essential AI topics.
   c. Redistribute the curriculum content by reorganizing topics, ensuring a balanced distribution of AI-related subjects throughout the grade levels. This redistribution should result in comprehensive coverage of AI topics throughout the curriculum and promote engagement and interest in AI concepts through exposure in earlier grade levels.
   d. Identify areas of AI that require more attention and expansion in the curriculum, considering emerging technologies, interdisciplinary connections and UNESCO's framework. This identification should help the curriculum remain up-to-date with AI advancements and provide a well-rounded education so that it can prepare students for future AI careers.

e. In accordance with UNESCO's framework for AI education, emphasize interdisciplinary connections, ethics and societal impact. The CCDI should integrate ethical considerations in AI development and deployment, promote a holistic understanding and application of AI concepts, and foster responsible AI use.

f. Conduct pilot programmes to test the enhanced curriculum, gather feedback and iterate based on insights gained. These pilot programmes should enable real-world testing and feedback, ensuring that the curriculum meets the needs of students and educators and allows for continuous improvement based on participants' comments.

g. Provide training and professional development opportunities for teachers and curriculum designers to effectively develop and deliver the enhanced framework, incorporating AI-related concepts and emerging technologies. This training should equip teachers and designers with the necessary skills to deliver high-quality instruction and develop engaging curriculum content. These include acquiring new tools, adapting to new writing styles, and modifying pedagogical approaches to enhance the curriculum.

h. Develop appropriate assessment methods and evaluation criteria to measure students' understanding and proficiency in AI concepts aligned with the enhanced curriculum. This will facilitate an evaluation of learners' progress and the curriculum's effectiveness, ensuring consistent standards and quality education.

i. Establish a system for continuous monitoring, feedback collection and evaluation of the enhanced curriculum's implementation, making necessary adjustments based on the findings. This system enables ongoing monitoring to keep the curriculum relevant and impactful, facilitates a feedback loop for continuous improvement and allows for adaptation to changing educational landscapes.

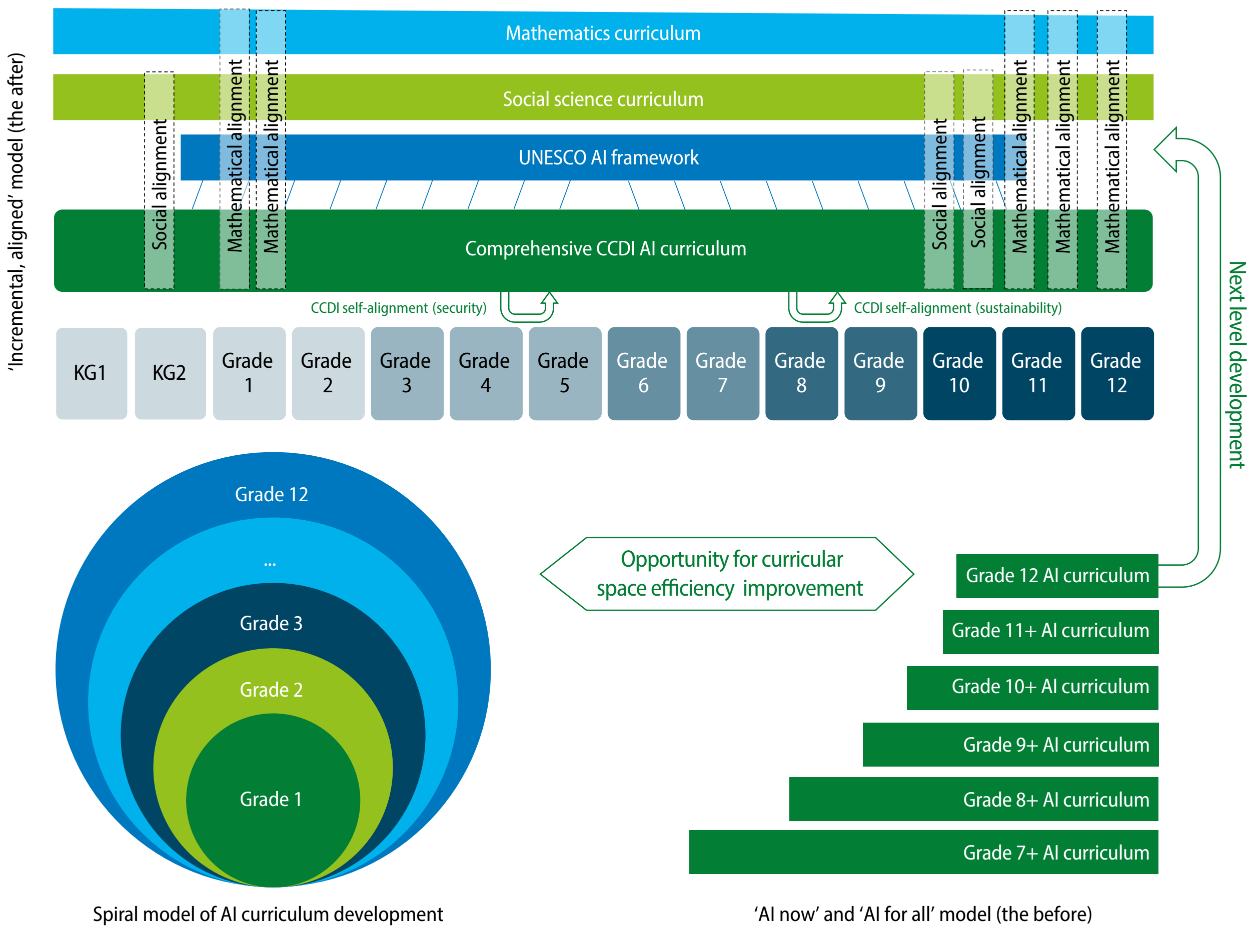
2. Align the curriculum with mathematics and science curricula:

To enhance the educational experience, the curriculum plan illustrated in **Figure 7.1** is recommended for thoughtful design using a spiral development approach. Each iteration features concepts at different grade levels with increasing difficulty and greater depth. This spiral approach aims to avoid delays in introducing critical future skills to students at all levels. For instance, within one academic year, a student in the first grade progresses through the curriculum, enhancing their existing AI knowledge in preparation for entering the second grade. Similarly, a senior student about to graduate is exposed to the same skill set but within a more sophisticated framework, setting them up for the next phase of their educational journey. Along the pathway of spiral development, opportunities for evaluating the coherence, efficiency, learning gaps, redundancies and alignment with mathematics, natural science and social studies curricula become prime for the taking. The figure demonstrates a spiral development at the early stage, ensuring that students from all grade levels are introduced to AI concepts before graduating, emphasizing 'AI now' or 'AI for all'. Moving to the next level of development, the figure highlights the alignment between the mathematics and social sciences curricula with the UNESCO AI framework, as identified in the *K-12 AI curricula* report (UNESCO, 2022). This comparison aims to assess government-sponsored curricula on a global scale. Furthermore, the UNESCO AI framework is mapped with the CCDI AI curriculum, promoting a coherent and integrated approach to AI education across K-12 schools. The CCDI AI curriculum would then facilitate mapping various topics already covered in K-12 schools to specific AI domains, including embedded systems and edge AI and AI applications in security, such as facial and sound recognition. This alignment ensures seamless integration of AI concepts with the existing educational framework, enabling students to explore AI-related topics within familiar subjects.

The CCDI is an embedded and interdisciplinary AI curriculum which seems to aim at empowering product and service development innovation. It features embedded systems, electronics, 3D printing, algorithms and programming, and security. The curriculum does not rely heavily on one particular technology and takes every opportunity to diversify the skills developed across different platforms, tools and technology providers. One of the domains covered in the CCDI is computer science. This domain covers various topics related to computing, such as computing systems, networks, data analysis, algorithms, programming and the impacts

of computing on society. Through this domain, students will understand how computers work and how to use them to solve real-world problems. Another domain covered in the CCDI curriculum is Visual communication. This domain focuses on technical graphics, CAD principles and 3D design realization. Students will learn to effectively create and communicate visual ideas using various design tools and techniques. The Engineering principles and systems domain covers topics related to electricity, electronics, robotics and embedded systems. Through this domain, students will develop a deep understanding of how technology works and how it can be used to improve people's lives. The Design and innovation domain focuses on entrepreneurship and the engineering design process, helping students develop creative thinking and problem-solving skills. Students will learn to develop new ideas, bring them to life, and collaborate to achieve a common goal through this domain. The Sustainability domain is a crucial component of the CCDI curriculum, covering topics related to building a sustainable society, such as environmental conservation, resource management and social responsibility. Students are introduced to sustainability concepts and learn how to apply them daily. The curriculum emphasizes sustainability's importance in local and global contexts and encourages students to become responsible global citizens.

Figure 7.1. Curriculum plan demonstrating the spiral development for the 'AI now' and 'AI for all' concepts and the next-level development plan



3. Consider universities' academic requirements when enhancing the CCDI to prepare students adequately for AI programmes and courses in higher education.
4. Improve the overall curricular topic flow to create a more coherent and structured learning experience, enabling students to connect different concepts and apply them in real-world scenarios:
   a. Analyse the existing curricular topic sequence and identify areas where the flow can be improved. This analysis helps identify disjointed or redundant topics, gaps in sequencing, and opportunities for improving coherence and structure so that students can better understand the logical progression of concepts and more effectively apply their knowledge to practical tasks.
   b. Restructure the curricular topics to create a more logical and seamless progression of concepts. Ensure that prerequisite knowledge is introduced before advancing to more complex topics, promoting a smoother learning experience. This restructuring improves the overall coherence, reduces cognitive load and increases engagement, enhancing comprehension and retention.
   c. Integrate interdisciplinary connections between AI and other subjects, such as mathematics, science and social studies. Emphasize the practical applications of AI in different domains to demonstrate the relevance and interconnectedness of concepts. This integration fosters a holistic understanding of AI's applications and its impact across various fields, as well as promoting critical thinking and problem-solving skills in diverse contexts.
   d. Incorporate project-based learning activities and practical exercises encouraging students to apply their knowledge in authentic situations. Design assignments and projects that require the integration of multiple concepts and promote hands-on exploration. These activities enhance students' ability to connect theoretical knowledge with practical scenarios. Project-based learning fosters creativity, collaboration and problem-solving skills, preparing students for real-world challenges.
   e. Provide clear learning objectives and outcomes for each curricular topic, making sure that students understand the purpose and relevance of their studies. Align the objectives with real-world skills and competencies to boost motivation and engagement. Clear learning objectives guide students' journey, enabling them to track their progress and stay motivated.
   f. Seek feedback from students and educators regarding the curricular topic flow and make adjustments based on their input. Regularly assess the effectiveness of the revised topic sequence and make necessary refinements. Feedback-driven improvements ensure that the revised flow meets the needs and preferences of students and educators. Continuous evaluation leads to an iterative enhancement process and an optimized learning experience.
5. Align the curriculum more closely with UNESCO's framework, prioritizing a well-rounded and interdisciplinary approach to teaching AI to better prepare students for future workforce demands. By incorporating the principles and perspectives outlined in the UNESCO framework, the curriculum can foster a comprehensive understanding of AI, encompassing technical knowledge, ethical considerations and societal impact. The *K-12 AI curricula* report (UNESCO, 2022) serves as a valuable guide, ensuring students receive a holistic education in AI that addresses the field's interdisciplinary nature and ethical implications. This approach equips students with the necessary skills and knowledge to navigate the complexities of the AI-related job market and make meaningful contributions to society.

7.1.2 Learning outcomes of CCDI curricula

Key findings

The mapping of the CCDI's learning outcomes to those in the UNESCO report shows that this curriculum can be improved. For example, the CCDI needs more attention to outcomes on creating chatbots, constructing robots, building and running statistical regressions, using NLP, rule-based reasoning, IoT operating systems, GANs, creating SQL scripts, understanding advanced technologies like cloud computing, and using AI to produce art and music. The CCDI curriculum also lacks coverage in certain areas of AI outlined in **Figure 4.8**: AI applications, contextual problem-solving, applications of AI to other domains and AI development.

Recommendations

1. Conduct iterative revisions of this mapping to improve the CCDI's coverage of the outcomes in the *K-12 AI curricula* report.
2. Redesign the delivery of the CCDI's learning outcomes to ensure that all outcomes from the *K-12 AI curricula* report are adequately covered and aligned with the framework.
3. Prioritize the areas where the CCDI outcomes do not align with the UNESCO framework.
4. Regularly evaluate and update the CCDI curriculum to ensure that it remains aligned with UNESCO's framework and reflects the latest developments in AI.

7.2 Delivery approach

7.2.1 Teacher training and support

Key findings

This study indicates that teacher training and support are critical components for successfully implementing AI curricula in K-12 education. Existing teaching staff may require additional training and upskilling to teach AI subjects effectively. The authors suggest that ongoing professional development opportunities, technological support, feedback, mentorship, collaboration, teamwork and recognizing and rewarding teachers' achievements are all important considerations in this regard.

Recommendations

1. Build a strong strategy to upskill existing teaching staff by conducting training initiatives or programmes for teachers of AI and other subjects that integrate AI topics.
2. Consider implementing the six suggestions for teacher training and support listed in section 5.1.

7.2.2 Learning tools and environments

Key findings

The case study indicates that the CCDI uses various technologies and tools to help create a more well-rounded learning experience that caters to the diverse needs of students, prepares them for future careers and fosters a deeper understanding of AI and its real-world applications.

Recommendations

1. Wherever possible, continue to invest in the necessary infrastructure to support a variety of AI technologies and learning tools in K-12 education. This includes providing basic infrastructure such as high-speed internet and computer hardware, and ensuring that teachers receive adequate training and support to use these technologies to achieve the desired learning outcomes.
2. Establish quality-assurance and performance-review mechanisms within schools to ensure the infrastructure is utilized effectively and efficiently. By doing so, schools can create a conducive environment for AI education that enables students to learn and apply skills relevant to the rapidly evolving field of AI.
3. Adopt the use of simulations in AI classes to enhance students' learning and engagement, promote collaboration and critical thinking, and help prepare students for real-world applications of AI.

7.2.3 Suggested pedagogies

Key findings

The study indicates that to create an engaging, interactive and relevant learning experience for K-12 students, educators use various pedagogies: design thinking, group work, collaborative learning, gamification, project-based learning, and activity- or task-based learning. These methodologies align well with the development levels and learning capabilities of students in each educational cycle, allowing them to gradually build up their understanding and abilities in a meaningful and practical way. In such a setting, the teacher is the moderator or facilitator while students develop their skills at their own pace. These skills include independence, exploration, experimentation and evaluation. Pedagogical approaches need to be flexible and adaptable, because not all students learn in the same way. It can be beneficial to add further strategies such as cross-curricular learning and peer mentoring.

Recommendations

1. Incorporate a combination of the pedagogical approaches that are applicable to teaching AI content in each cycle in order to enhance and refine the necessary skills of the students. Consider utilizing a blend of the following:

- Cycle 1:
  > Play-based learning (Pyle and Danniels, 2017), which allows students to experiment with educational games and toys that incorporate simple AI concepts, such as voice recognition.
  > Storytelling and creative expression, which allows students to imagine and create AI-powered characters or interactive stories.
  > Hands-on activities, such as building and programming robots, that teach basic coding and computational thinking skills through trial and error.
  > Inquiry-based learning (Pedaste et al, 2015), which encourages students to ask questions and investigate AI concepts and their applications.
  > Collaborative learning (Chang et al., 2022) that allows students to work in groups to design and build AI-powered projects, such as robots or games.
  > Project-based learning (Mursid et al., 2022), which allows students to apply AI concepts to real-world problems and scenarios, such as analysing sensor data.

- Cycle 2:
  > Problem-based learning that challenges students to solve AI problems and design their solutions.
  > Student-led learning that allows them to explore their interests and passions within the field of AI, such as by pursuing a project of their choice.
  > Reflective learning that encourages students to think critically about the ethical and societal implications of AI and to consider their values and beliefs about the technology.

- Cycle 3:
  > Experiential learning that involves hands-on practice with AI technologies and tools, such as machine-learning models.
  > Collaborative exploration and innovation that allows students to work with others in the field, such as through participation in hackathons or competitions.
  > Self-directed learning that allows students to take ownership of their learning, pursue their questions and develop their own AI applications.
  > Authentic assessment that evaluates learning through real-world projects and performance-based tasks, such as developing and programming robots.

2. Consider leveraging blended learning, including traditional classroom teaching, online resources and self-directed learning, to provide students with a flexible and personalized learning experience. This approach can cater to different learning styles and allow students to make progress independently.
3. Integrate inquiry-based learning to empower students to ask questions and explore AI topics in depth through experimentation and collaboration with peers. This approach encourages curiosity, creativity and independent thinking.

7.2.4 Summative assessment

Key findings

The study team had the opportunity to scrutinize a series of CCDI assessment samples from cycle 3, encompassing grades 9 to 12. These included both formative and summative assessments referred to as 'checkpoints', with a set of files including an assessment guide, detailed specification, marking rubric, activity document and sheets for tracking attendance and progress. These assessments are high quality and comprehensive, and adhere to the methodology outlined in **Figure 7.2**.The majority of the samples were not specific to AI but cover a range of subjects in the CCDI curriculum. The assessment formats observed in the samples included programming projects, examinations and presentations, all of which are suitable for an AI curriculum. Research papers and posters were not represented in the samples but may constitute another useful format.

Recommendations

1. Consider the inclusion of research papers or posters as a type of summative assessment for the AI curriculum. These may discuss current AI topics such as AI's application in health care or its ethical ramifications for self-driving vehicles.
2. Use the six steps listed below and shown in **Figure 7.2** to think through the process of designing summative assessments to ensure accurate measurement of students' learning and achievement:

Figure 7.2. Summative assessment process

- Define learning objectives: The first step in creating any assessment is to have a clear understanding of the learning objectives. These should align with both the content and skills to master. In the context of AI, this may include understanding basic AI concepts, programming skills and ethical considerations.
- Determine assessment format: Decide the format that best suits the learning objectives. This could be a combination of multiple-choice questions, short answers, essays or project-based assessments (e.g. where students create a simple AI model to demonstrate their programming skills).
- Design questions or tasks: For instance, an instructor might ask students to code an AI algorithm, explain how a neural network works or discuss the ethical implications of AI.
- Design scoring rubrics: Design detailed rubrics for each assessment to clarify the expectations and provide a fair, transparent method for scoring student work. For a project, this might include criteria like correctness of code, creativity, completeness of the project and understanding of AI principles.
- Include formative assessment: Although the focus is on summative assessment, it is beneficial to include formative assessments as well. These provide students with feedback during the learning process and can help instructors adjust instruction if needed. In-class activities or draft reviews of projects could serve as formative assessments.
- Review and refine: After students take the assessment, instructors should review the results to see if they align with expectations. If students are generally scoring low on a certain topic, that might indicate a need for more instruction in that area. Over time, instructors will refine the assessments to better align with the learning objectives.

7.3 Curriculum relevance

Key findings

The CCDI curriculum was found to cover most of the identified competencies, with a particular emphasis on machine learning, data analysis and robotics. It provides an early introduction to key AI concepts, programming languages and tools, which helps students build a strong foundation for further studies. Therefore, the curriculum's ability to prepare and motivate students for higher education is evident. Additionally, the CCDI is on par with international curricula and practices.

Based on the analysis and feedback, we have identified areas of the curriculum that may need improvement, such as gaps in the alignment with labour market needs, and international standards and practices. The curriculum must cover AI-related technologies and soft skills in sufficient depth to prepare students for advanced courses in higher education. The framework also needs to include further practical projects to enable students to apply their knowledge in real-world scenarios.

Recommendations

1. Continue to emphasize the importance of ethics and AI governance and ensure that these topics are integrated throughout the curriculum.
2. Strengthen project-management skills by incorporating practical, real-world AI projects that require students to collaborate and apply their learning.
3. Continuously update the curriculum to reflect the rapidly evolving field of AI and ensure that it remains relevant to the labour market and higher education requirements.

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United Nations
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AI in the United Arab Emirates' computing, creative design and innovation K-12 curriculum

A case study

The UAE has integrated AI into its K-12 curriculum since 2017 to enhance learning and critical thinking. The initiative prepares students for a technology-driven job market and reflects the UAE's innovative approach. This evaluation of the computing, creative design and innovation (CCDI) curriculum compares it with global AI curricula and job market needs. The curriculum aligns with UNESCO's goals, focusing on ethics and practical AI aspects. It emphasizes technical skills, data literacy and ethics, and readies students for AI-related higher education. Suitable tools, teacher training and supportive environments are crucial for effective AI curriculum implementation in K-12 education. Strategies include teacher upskilling, expanding curriculum in data analytics and AI libraries, and gradual skill introduction. Integrating AI into existing subjects prepares students for an AI-shaped future. This case study highlights strengths, teacher training importance, alignment with job market needs, ethics and global AI education standards.

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